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OCTOBER 2023

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The rocky Earth-sized planet HD 85512 b orbits a main sequence star and has a mass at least 3.6 times that of Earth. ESO/M. KORNMESSER/
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Everything you need to know this month: long-wavelength gravitational waves detected, Milky Way imaged in neutrinos, phosphate found on Enceladus, and more!

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Follow the Milky Way



Astronomy's newest associate editor, Daniela Mata.

DYNA IBRAHIM



Astronomy is unique among the sciences in that the laboratory the highest-level professionals use is also available to us all. To access it, all we need do is get away from city lights to a dark sky, and the universe opens up in all its glory.

Observers are no doubt familiar with the rich area of the sky in Sagittarius, Scorpius, and Serpens. When we look toward the summer Milky Way — which is still visible now, in the evening sky of autumn — we gaze toward the center of the galaxy. Countless star clusters and nebulae await binoculars and telescopes and eyes eager to explore.

This month, Kevin Ritschel takes us through some of that exploration in “Explore Great Summer Nebulae” (page 38). He focuses on a region surrounding two bright and legendary star-forming regions, the Eagle Nebula and the Omega Nebula. I'm sure you know about the former, as it contains the dusty “Pillars of Creation” made famous in those images taken with the Hubble Space Telescope.

But many other objects await. An off-the-beaten path exploration of this area, and many others like it, will reveal innumerable friends you can visit in your scope's eyepiece, returning to them time after time, contemplating the big galaxy and universe we live in.

On a staff note, I ask you to please welcome *Astronomy's* newest associate editor, Daniela Mata. Daniela obtained her B.S. in mathematics from Texas A&M International University and a master's degree in astrophysics at Université Côte d'Azur in Nice, France, where she specialized in galactic archaeology. For her final internship, she focused on retrograde metal-rich stars in the Milky Way, classifying their origins. She also studied populations of stars near the galactic center.

Now a resident of Milwaukee, Daniela joins the editorial team to commence the brand's second half-century in existence. We look forward to her participation in many exciting adventures to come.

Yours truly,

David J. Eicher
Editor



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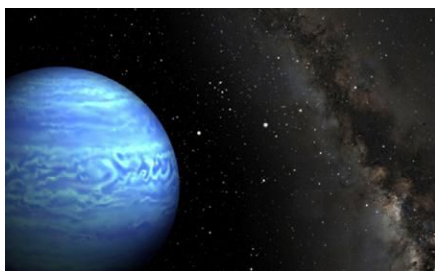
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The brown dwarf WISE J085510.83-071442, shown in this artist's concept, is the fourth-closest stellar system to Earth. NASA/JPL-CALTECH/PENN STATE UNIVERSITY

Dwarfed stars

I read the June 2023 article "Explore the 10 nearest stars" with interest and some dismay. I thought, "What about the surprising new additions to the local family of stellar systems, the brown dwarfs?" An account of them was entirely missing. For instance, the brown dwarf binary pair Luhman 16 is just 6.5 light-years from Earth, third place

in distance after Barnard's Star. And there is another brown dwarf, designated as WISE 0855-0714, at 7.43 light-years, fourth closest to Earth and a little nearer than Wolf 359 (7.85 light-years). Out of the four nearest stellar systems, two are brown dwarfs. A more complete picture of what our nearest stellar neighbors are like is important to our understanding of what kind of stars populate our galaxy — and other galaxies too.

— Robert Flippin, South Gate, CA

Senior Editor Mark Zastrow responds: Good point, Robert. That story was meant to be a series of profiles of

individual stars. But while brown dwarfs are not stars, as they can't fuse hydrogen to helium, they are certainly crucial in understanding this neck of the galactic woods — and worth exploring in their own feature story.

Wonderful Webb

"How the Webb Telescope is changing astronomy" by Richard Talcott (June 2023) is an outstanding description of the details which have been revealed, as well as a concise tour of how they have been accomplished. There is no doubt that JWST is opening new vistas in the eyes of astronomers. The third paragraph is the best explanation to date of how JWST differs from Hubble and why it makes a difference. Excellent writing is its own reward and should be recognized.

— Donald Craig, Jr., Indianapolis, IN

Erratum

Michael Bakich's June 2023 article "First look at October's Annular Eclipse," states "Texas first gets annularity at 11:41 P.M. CDT." The annularity in Texas will actually be at 11:41 A.M. CDT.

→ We welcome your comments at *Astronomy Letters*, P.O. Box 1612, Waukesha, WI 53187; or email to letters@astronomy.com. Please include your name, city, state, and country. Letters may be edited for space and clarity.



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SNAPSHOT

GREAT BALLS OF FIRE

One year on, JWST continues to deliver images of intense beauty.

A blazing inferno lights up the Rho Ophiuchi cloud complex in this image taken by the James Webb Space Telescope (JWST), published to celebrate the one-year anniversary of the release of its first science images. The picture reveals dynamism in a relatively quiet star-forming region 390 light-years from Earth in the constellation Ophiuchus the Serpent-bearer. The portion of the complex imaged by JWST contains 50 stars the mass of our Sun or smaller. However, the glowing sun dominating the lower part of the picture and surrounded by chaotic swirls of hot dust is a much larger star. To the upper right are red-colored jets composed of molecular hydrogen streaming out from opposing ends of newly formed stars. The dark, dense clouds are thick dust enclosing forming protostars. Although difficult to see, shadows surrounding a few of the stars are signs of protoplanetary disks, an indication of burgeoning planet formation. —SAMANTHA HILL



HOT BYTES



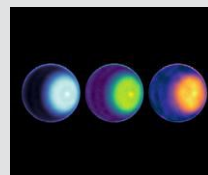
TWO OF A KIND

Pulsars are almost always rapidly rotating neutron stars, remnants of supernovae. But in June, astronomers reported the second known white dwarf pulsar, thought to have spun itself up by siphoning matter off a companion star.



ASTRONOMY'S CHRONICLER

Owen Gingerich, professor emeritus of astronomy and the history of science at Harvard University, died May 28 at the age of 93. He was one of the world's most respected authorities on the history of astronomy — especially Nicolaus Copernicus, who proposed the heliocentric universe.



POLAR VORTEX

Scientists have found the first strong evidence of a polar cyclone swirling around Uranus' north pole, thanks to data from the Very Large Array in New Mexico. The storm features a core of warm, dry air, similar to vortices seen around the poles of Saturn.

THE GREAT HUM: GRAVITATIONAL WAVES CONTINUOUSLY RIPPLE ACROSS SPACE-TIME

Radio astronomers have detected long-wavelength gravitational waves for the first time.



» The universe is continuously rippling with gravitational waves, a 15-year survey has reported. Using pulsars as distant beacons and radio telescopes to plumb the galaxy, a massive collaboration of astronomers and physicists found strong evidence of a gravitational-wave background undulating through the cosmos. A single wave may take years or even decades to crest and fall.

The detection of these background gravitational waves is a long-awaited result. Scientists think these waves largely result from pairs of supermassive black holes at the centers of merging galaxies, with some contribution possibly from the Big Bang itself. The

ability to measure these waves directly should inform scientists about the origin and history of the universe.

The results were published June 28 in a series of papers in *The Astrophysical Journal Letters* and were based on collaborative efforts between the North American Nanohertz Observatory for Gravitational Waves (NANOGrav), researchers with the International Pulsar Timing Array, and international collaborators in India, Australia, Europe, and China.

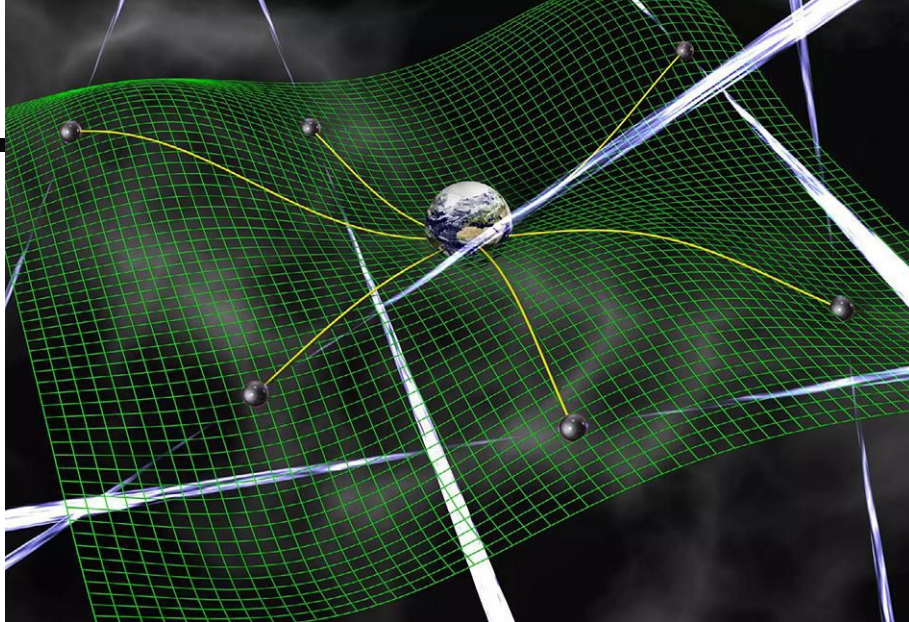
"This is key evidence for gravitational waves at very low frequencies," said Stephen Taylor, a gravitational-wave astrophysicist who co-led the research at Vanderbilt University in Nashville,

TWO TO TANGO. Pairs of supermassive black holes generate gravitational waves that permeate the cosmos, depicted in this illustration. AURORE SIMONNET FOR THE NANOGrAV COLLABORATION

in a statement. "After years of work, NANOGrav is opening an entirely new window on the gravitational-wave universe."

A HUM IN SPACE

When gravitational waves pass, they cause space-time, or the fabric of the universe, to ripple like a wiggling waterbed. Binary systems of massive objects like black holes and neutron stars create these waves. As the objects spiral toward each other and their accelerations increase, they send off energy as gravitational waves.



COSMIC CHOP. The gravitational-wave background distorts space-time like waves on a sea. Researchers have detected these waves by studying how their passage alters the timing of the arrival of pulsar signals at Earth. DAVID CHAMPION/MAX PLANCK INSTITUTE FOR RADIO ASTRONOMY

The first-ever detection of gravitational waves was reported in 2015 by researchers at the Laser Interferometer Gravitational-wave Observatory (LIGO), a set of mile-long observatories in Washington and Louisiana. But the signals observed by LIGO and subsequent similar facilities can only detect gravitational waves that resonate at high frequencies generated by relatively small objects — merging neutron stars or black holes born from single supernova explosions.

Scientists have long predicted another form of gravitational waves — a continuous hum produced by pairs of supermassive black holes, each with the mass of millions to billions of Suns, slowly spiraling toward each other. These lower-frequency gravitational waves — too low for LIGO to detect — form a gravitational-wave background, rumbling from all over the universe at the speed of light and gently buffeting Earth from all directions.

“Like a huge ocean swell, the stars in our galaxy are all moving in concert to waves in space-time that take more than a decade just to complete one cycle of the wave,” says Kelly Holley-Bockelmann, a Vanderbilt astrophysicist who was not involved with the studies.

“What NANOGrav was looking for was the signature of the coalescence of those supermassive black holes at the center of massive galaxies,” says Gabriela González, an astrophysicist at Louisiana State University and member of the LIGO Scientific Collaboration, also not involved with the studies. The many signals come from different points in the

universe and create a rumbling hum, like noise in a crowded room. “It’s not the individual signatures, individual signals as we see in LIGO, but all together, all mixed up,” González says.

COSMIC TIMEKEEPERS

The long timescales of low-frequency gravitational waves make them tough to detect. NANOGrav’s strategy is to use pulsars within a section of the Milky Way Galaxy as a colossal gravitational-wave antenna. Pulsars are rapidly rotating stars — typically neutron stars — that send out beams of radio waves like a spinning beacon in space. Every time the pulsar flashes its beam toward Earth, we detect a pulse of radio waves, up to hundreds of times per second at regular intervals.

But rippling gravitational waves can alter their timing, causing signals to arrive very slightly behind or ahead of schedule, allowing researchers to pinpoint a pattern associated with the waves. Researchers from all over the globe compiled data from 68 pulsars to create NANOGrav’s pulsar timing array, aimed at detecting these small variations.

There were four observatories involved in the effort, though two did the bulk of the work: the Green Bank Telescope in West Virginia and the now-defunct Arecibo Telescope in Puerto Rico. Two other radio arrays — the Very Large Array in New Mexico and the Canadian Hydrogen Intensity Mapping Experiment (CHIME) in British Columbia — also contributed observations. — ELIZABETH GAMILLO

QUICK TAKES

BEFORE THIS DECADE IS OUT

Lin Xiqiang, deputy director of the China Manned Space Agency, said May 30 that China has set the goal of landing astronauts on the Moon before 2030. The statement came one day after China launched a crew of three to the Tiangong space station for a five-month mission — the first since the station became fully operational.

TINY HOMES

Laboratory tests indicate DNA and RNA molecules can survive inside sulfuric acid droplets in Venus’ clouds. The team responsible includes members of the group that reported the controversial detection of phosphine, a possible biosignature, in the venusian atmosphere.

JOURNEY TO THE DARK SIDE

The European Space Agency’s Euclid mission launched June 30 from Cape Canaveral aboard a SpaceX Falcon 9 rocket. The telescope will survey over a third of the sky and map billions of galaxies to study gravity’s role in the universe and the behavior of dark energy and dark matter.

BEAM IT DOWN

A Caltech prototype satellite has performed the first demonstration of collecting solar power and beaming it wirelessly from orbit to a ground station. The team hopes this is an initial step to tapping the power of the Sun in space to meet Earth’s energy needs.

TUNE IN, DROP OUT, AND EXPLODE

In a first, astronomers have detected radio-wave emission from a type Ia supernova — the explosive death of a white dwarf stealing matter from a binary companion. The radio waves are thought to emanate from shock waves as the explosion travels through some of the pulled-off material. — MARK ZASTROW

Milky Way imaged in neutrinos

A DECADE OF DATA from the IceCube Neutrino Observatory at the South Pole has allowed astronomers to view the Milky Way not in light, but in particles. The resulting image, a first, was published June 29 in *Science*.

"This is the first time we are viewing our galaxy in something other than light," says Naoko Kurahashi Neilson, a particle physicist at Drexel University in Philadelphia who has been working at IceCube for over a decade.

Because neutrinos rarely interact with matter, by observing them astronomers can pierce the dust that permeates galaxies and shrouds black holes. But this noninteractive nature also makes neutrinos hard to detect. IceCube tackles this with 5,000 optical sensors that have been lowered into the Antarctic ice on strings into drill holes up to 8,000 feet (2,450 meters) deep. If a high-energy neutrino from space strikes the nucleus of an atom in the ice, it breaks down into an array of highly energetic particles that radiate light. The optical sensors capture this light and a machine-learning algorithm processes the data and reconstructs where the neutrino came from in space.

Since IceCube's establishment in 2011, the observatory has recorded over a million neutrinos, but none had been confirmed as originating in our own galaxy. That's because the easiest neutrinos to trace leave a linear, tracklike path of light through the ice — and they belong to objects far away, outside the Milky Way.

Neilson and her colleagues tried looking for a different kind of neutrino signal, a more diffuse cascade resembling a blob of light. It's difficult to locate the direction these signals come from, and they had been generally ignored.

But the team was able to identify hundreds of neutrinos that appear to come from the plane of the Milky Way. Converted into an image, it shows which areas of our galaxy produce high-energy neutrinos.

What's more, the resulting image closely corresponds with gamma-ray images of the galaxy. This provides insight into how galactic neutrinos are produced. When cosmic rays — fast-moving atomic nuclei generated in high-energy or cataclysmic objects — strike gas and dust in the galaxy, they should produce both gamma rays and neutrinos. Astronomers

PHOSPHATE ON ENCELADUS BOOSTS CHANCES FOR LIFE

ACCORDING TO LEGEND, the ancient giant Enceladus vents sulfur from his tomb. According to data, Saturn's tiny moon Enceladus vents more than that.

In a new analysis of data from the retired Cassini mission to Saturn, an international team of researchers has detected phosphorus — a key ingredient for life — coming from Enceladus' warm, salty subsurface ocean.

Enceladus is now the only other place in the solar system besides Earth with compelling evidence for all six of the most critical elements needed for life: carbon, hydrogen, nitrogen, oxygen, phosphorus, and sulfur. Phosphates are critical to life's most important molecules — DNA and RNA — as well as to walls of cells.

The study was led by Frank Postberg, a planetary scientist at the Free

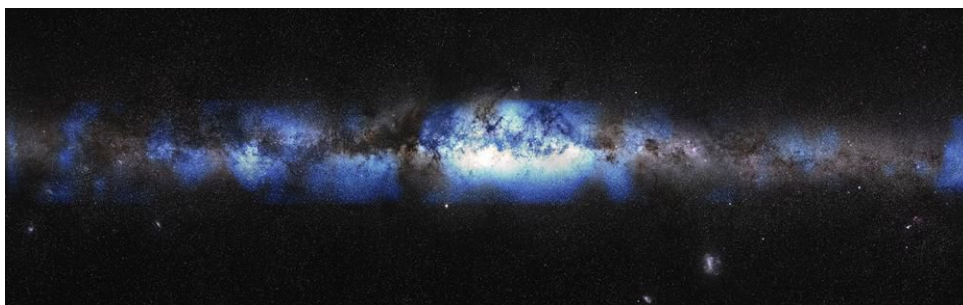
had already seen gamma rays they thought were created this way; now, the neutrinos that should also result have been spotted.

As development of detector technology and machine-learning techniques continue, neutrino-based images will only grow clearer. "Hopefully, in another 10 years, I can come back with a NASA-quality picture of the entire universe, not in light, but in neutrinos," says Neilson. "This is the goal of my career." — ANANYA PALIVELA

1.72

The number of inches (4.36 cm) the geographic North Pole moves every year due to human use of groundwater, per researchers' calculations.

Pumping groundwater up from aquifers — including for drinking, irrigation, and industry — alters Earth's mass distribution and axial tilt.



NEW LIGHT. The Milky Way as seen in neutrinos is superimposed in blue on a visible-light image in this illustration. ICECUBE COLLABORATION/U.S. NATIONAL SCIENCE FOUNDATION (LILY LE & SHAWN JOHNSON)/ESO (S. BRUNIER)

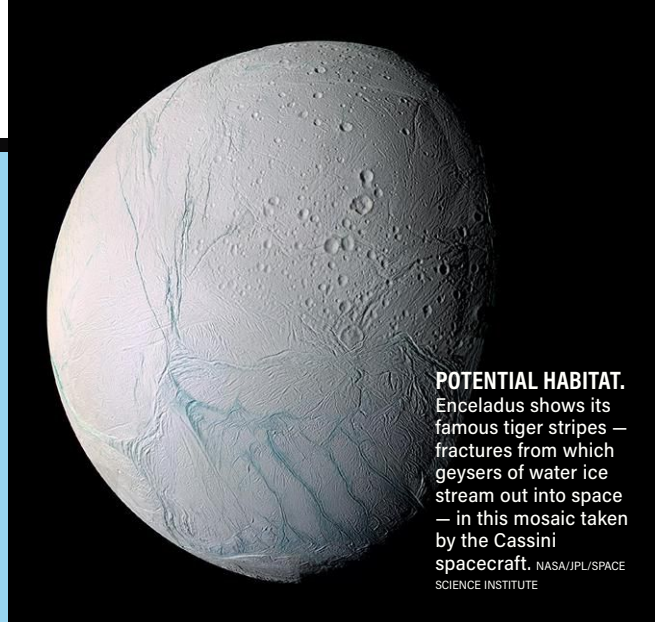
University of Berlin in Germany, and published June 14 in *Nature*. The analysis found that the concentration of phosphates in Enceladus' ocean is at least 100 times that in Earth's seas.

Postberg tells *Astronomy* that while further work is needed to determine the exact amount of phosphorus present at Enceladus, he thinks the detection is "absolutely bulletproof." Even better, he adds, is that the phosphate found there is soluble, meaning it can dissolve in water and is therefore available for use by any possible life.

The team found the sodium phosphate in data Cassini took as the spacecraft

flew through the moon's plume of water ice, which vents from geysers near Enceladus' south pole. It also showed up in the E ring, a diffuse ring of Saturn that is fed by the plume. The detection, using Cassini's Cosmic Dust Analyzer, was impressive considering the instrument wasn't designed for such a detection.

"Although this discovery was consistent with our previous geochemical models, I was still shocked," says study co-author Christopher Glein, an extraterrestrial oceanographer at the Southwest Research Institute in San Antonio, Texas. "Frank might have been the only person in the world who



POTENTIAL HABITAT. Enceladus shows its famous tiger stripes — fractures from which geysers of water ice stream out into space — in this mosaic taken by the Cassini spacecraft. NASA/JPL/SPACE SCIENCE INSTITUTE

thought this was possible, and he pulled it off."

Nathalie Cabrol, an astrobiologist who wasn't involved with the work, ranked her excitement over the detection as off the charts: On a scale from one to 10, she called it a 20. "Enceladus is

habitable for life as we know it," says Cabrol, the director of the Carl Sagan Center for the Study of Life in the Universe at the SETI Institute in Mountain View, California. "This little world is really tantalizing." —CHRISTOPHER COKINOS

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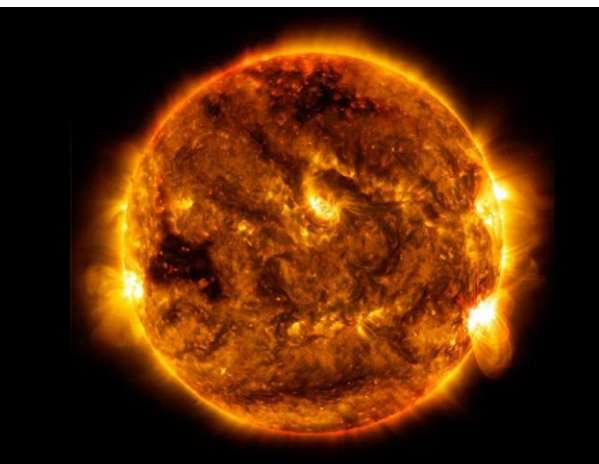
EclipseTraveler

Astronomy

P41360

Astounding fundamentals

Add to your list of amazing astro facts.



The Sun provides necessary energy for life on Earth, thanks to its powerful but compact core, which takes up just 1/500,000 of our star's volume. NASA/SDO



It's not just observing star clusters or planets that creates delight. Celestial knowledge can be just as exciting, especially when it comes with weighty implications. This month, let's consider 10 basic astronomy truths. Perhaps you already know some of these facts — after all, I've explored about half of them on this page in the past decades, so keen readers may remember them!

But many are unfamiliar to most people, so award yourself 3 grams of lunar regolith for each of these you know.

1 One could say there are actually two universes. Everything from where you now sit out to a distance of 46 billion light-years is the visible universe, also called the observable universe. It constitutes everything we can ever see and know. Beyond that point begins the other universe: the *unobservable* universe. We know nothing about it because none of its light can ever get here. Space's large-scale flat topology shows that the "other side" is vast and maybe even infinite.

2 The possibility of countless other universes — the multiverse idea — presumes they exist in dimensions beyond the four we're familiar with. But there's never been any evidence for extra dimensions.

3 Life on Earth depends on the Sun. But the real key is a tiny solar component just 1/500,000 the Sun's total volume: its core. Seen separately, it would appear as a blindingly dazzling starlike pinpoint from Earth. Each second, it unleashes the energy of 96 billion 1-megaton H-bombs.

4 Most gravitationally connected bodies orbit in elliptical paths, making that geometric shape a true cosmic underpinning. Pound two nails into plywood and loosely drape a loop of string around them both. Tightly pull a marker outward against the string and you'll draw an ellipse. Each nail is called a focus. In every planet's orbit in our solar system, the Sun

occupies one focus. The other is just an empty spot of space.

5 The Moon's most abundant element is oxygen, albeit always bound to another element.

6 Empty space seethes with power. We have more names than knowledge about it. It's been called vacuum energy, dark energy, the cosmological constant, and zero-point energy. This energy supposedly randomly creates particles and antiparticles that briefly appear and then vanish, but this has never been observed.

7 It's widely repeated that Nicolaus Copernicus was the first to declare that Earth orbits the Sun. This truth is even termed the Copernican system. But some 17 centuries earlier, Aristarchus on the Greek island of Samos was applauded for saying the same thing.

8 Meteors are slowed so much by our atmosphere that if they strike anything on the ground, their impact speed is just 250 to 300 mph (400 to 480 km/h), down from their original typical entry speed of 80,000 mph (128,700 km/h). That's why famous recent meteorites have merely penetrated a roof and a ceiling (1971, 1982, and even 2023), caused a simple bruise when it hit someone (1954), and penetrated a parked car's sheet metal (1938, 1992). And they're never hot when they land.

9 Looking for easy rebuttals to common conspiracy beliefs? When someone says, "It was a hoax; we never went to the Moon," just ask, "Then where did those Saturn rockets go after liftoff?" If they'd merely orbited Earth, they would have been brightly visible to everyone. Plus, our adversaries tracking them on radar would have happily spilled the beans. To those who insist Earth is flat, just say, "Phone any friend who lives a few thousand miles to your west and ask them where they now see the Sun. If it's setting at your location but they're viewing it up high, Earth must be round. Simple."

Let's consider 10 basic astronomy truths.

10 Although many think the ET issue boils down to whether or not we're alone in the cosmos, it's not so black-and-white. Some people — such as Nobel-Prize-winner Werner Heisenberg — were convinced we're manifestations of a single awareness that is the universe's basic nature, since consciousness is not derivable from any other component. By such reasoning, there are no "others."

One of astronomy's benefits is the vastness of its subject. What's your own list of the most amazing or surprising facts about the cosmos? Share them! ▶



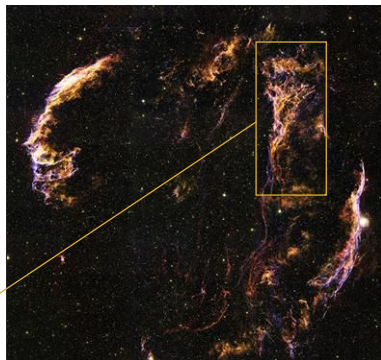
BROWSE THE "STRANGE UNIVERSE" ARCHIVE AT www.Astronomy.com/Berman



BY BOB BERMAN
Bob's recent book, *Earth-Shattering* (Little, Brown and Company, 2019), explores the greatest cataclysms that have shaken the universe.

Fleming's Triangular Wisp

When observing the Veil, don't overlook this ghostly feature.



LEFT: Fleming's Triangular Wisp is imaged here with the National Science Foundation's Mayall 4-meter telescope at Kitt Peak National Observatory (KPNO). RIGHT: The wide-field view of the Cygnus Loop was taken with the WIYN 0.9-meter at KPNO. Wide: T.A. RECTOR (UNIVERSITY OF ALASKA ANCHORAGE) AND WIYN/NOIRLAB/NSF/AURA. CLOSE-UP: T.A. RECTOR/UNIVERSITY OF ALASKA ANCHORAGE, H. SCHWEIKER/WIYN AND NOIRLAB/NSF/AURA

→ The Cygnus Loop is one of the most spectacular examples of a veiled stellar corpse that is accessible to small telescopes. Its visible streamers form the filamentary remains of an unknown supergiant star that erupted as a

supernova some 5,000 to 8,000 years ago.

Most observers enjoy seeking out the Loop's brightest segments, NGC 6992 and 6960. But did you know that the Loop's lesser ghostly wisps also are within reach of small telescopes? The most conspicuous of them carries no proper classification. Known as Fleming's Triangular Wisp, this phantom feature is one of the longest and most lacelike structures in the complex, and it may have contributed to the Loop's popular moniker: the Veil Nebula.

Williamina Paton Stevens Fleming (1857–1911) discovered this 3°-long rivulet of nebulous streamers while examining photographic plates. Fleming was one of the most celebrated woman astronomers at Harvard College Observatory (HCO). Aside from recording stars for the Henry Draper Catalogue, her work led to the discovery of 10 novae, 52 nebulae (including the Horsehead Nebula in Orion, the White-Eyed Pea

Nebula [IC 4593] in Hercules, and planetary nebula IC 2149 in Auriga), and 310 variable stars.

Fleming discovered the Triangular Wisp on Jan. 13, 1905, while examining a 240-minute exposure taken Sept. 2, 1904, at Harvard's outpost in Arequipa, Peru, with the 24-inch Bruce Telescope. (The telescope was named after Catherine Bruce, who gifted the money for its purchase.) On the glass plate's sleeve, Fleming refers to the find in the third person, writing: "Nebulosity marked by W. P. Fleming. Almost Complete Circle."

HCO Director Edward C. Pickering announced Fleming's discovery in *Harvard Circular* volume 111, dated Feb. 16, 1906: "From an examination of this plate, Mrs. Fleming found that the northern and perhaps southern ends of [NGC 6960 and 6992] are connected by faint nebulosity forming an irregular oval. A large triangular wisp of nebulosity extends southward, from the north preceding portion of this oval, and is much more conspicuous than the neighboring nebulae, NGC 6974 and NGC 6979."

Pickering's note clarifies that Fleming's Triangular Wisp is not NGC 6979, as it is sometimes attributed today. Both Fleming's original note and Pickering's announcement also clarify that Fleming was the first person to detect the Cygnus Loop.

Observing the wisp

Through a small telescope, Fleming's Triangular Wisp is a haunting spectacle. Its ghostlike visage floats between the braided fishhook of nebulous streamers to the east (NGC 6992/5 and IC 1340) and the bristling sweep of nebulosity known as the Witch's Broom to the west (NGC 6960).

The visual challenge is to use moderate powers to detect filamentary structure in the triangular head.

Can you trace the veil to its southern extreme, where it appears to curve westward? From a dark site, the entire inner arc is prominent enough to fool an unwary observer into believing that they have seen the Veil's easternmost segment. The perceived dimensions of these fainter features are tentative because they tend to follow star streams, and it is hard to judge where the nebulosity ends and the star streams begin.

A veil seems like a fitting label for these nebulous streamers, and not just for its appearance: Bridal veils date to Roman times, when they were used not only in marriage but in death as a burial shroud — appropriate for the remains of a stellar corpse.

As always, send your observations and thoughts to sjomeara31@gmail.com. ☛

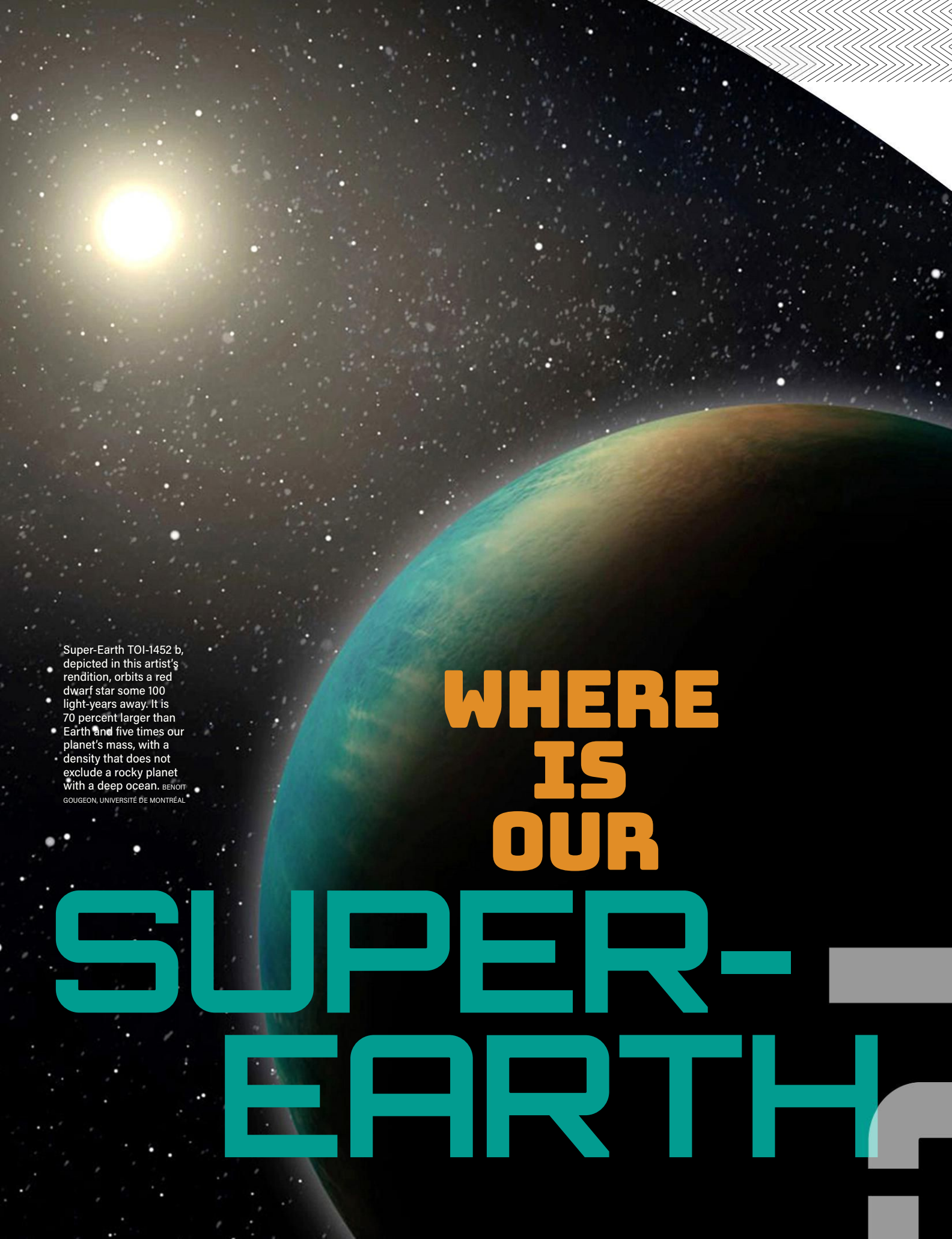
Fleming's Triangular Wisp is a haunting spectacle.



BY STEPHEN JAMES O'MEARA
Stephen is a globe-trotting observer who is always looking for the next great celestial event.



BROWSE THE "SECRET SKY" ARCHIVE AT
www.Astronomy.com/OMeara

An artist's rendering of a celestial scene. In the upper left, a bright, glowing yellow-orange star (a red dwarf) is the source of light. Below and to the right, a large, curved horizon of a planet is visible. The planet's surface is a mix of green and brown, suggesting land and water. The background is a deep black space filled with numerous small, distant stars. In the top right corner, there is a decorative pattern of white, overlapping, wavy lines. The overall composition is dramatic and emphasizes the vastness of space.

Super-Earth TOI-1452 b, depicted in this artist's rendition, orbits a red dwarf star some 100 light-years away. It is 70 percent larger than Earth and five times our planet's mass, with a density that does not exclude a rocky planet with a deep ocean. BENOÎT GOUGEON, UNIVERSITÉ DE MONTRÉAL

**WHERE
IS
OUR**

**SUPER-
EARTH**

The planets astronomers see often around other stars are strangely absent from our own solar system.

We're still figuring out why. BY APRIL RUSSELL

LOOK UP AT THE NIGHT SKY and among the stars you might see a few brighter dots — the planets in our solar system. What you won't see, though, are the most common kinds of planets in the Milky Way: super-Earths and sub-Neptunes.

These worlds, with sizes between that of Earth and Neptune, account for about one-third of known exoplanets. But they are absent from our own cosmic neighborhood. Why they don't appear around the Sun is an intriguing question that astronomers are now working to answer.

DEFINING PLANETS

To explore this mystery, astronomers must understand what these planets are like and how they fit into the architecture of planetary and solar system formation.

Super-Earths and sub-Neptunes are worlds with two to 10 times Earth's mass, and radii between those of our

planet and Neptune. (Although more massive than Uranus, Neptune's radius is roughly four times that of Earth, smaller than its fellow ice giant.) The terms *super-Earth* and *sub-Neptune* are sometimes used interchangeably, but many astronomers use the size of a planet's atmosphere relative to its amount of rock to differentiate between them. Rocky planets up to 1.75 Earth radii with a relatively small atmosphere are considered super-Earths, while sub-Neptunes generally have radii between 1.75 and three times Earth's, and host thick atmospheres with a smaller rocky core.

These definitions are still evolving, though. Johanna Teske of the Carnegie Earth and Planets Laboratory in Washington, D.C., says that researchers aren't sure whether atmospheres are the best way to determine the two categories, or if other factors, such as core size, are also meaningful.

We do know that super-Earths and sub-Neptunes vary in composition, from rocky to icy to gaseous and anything in between. We know they can have atmospheres, though whether they might host oceans or moons remains the subject of speculation.

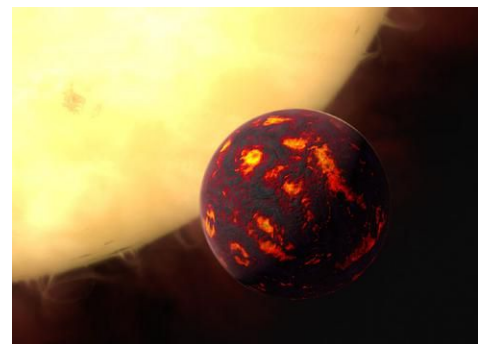
But these intriguing worlds do seem to be abundant.

FINDING OTHER WORLDS

Although scientists long believed that exoplanets existed, it is only in the past three decades that technology has caught up with our desire for discovery. Astronomers have found thousands of exoplanets since the mid-1990s, with 1,661 classified as super-Earths as of this writing.

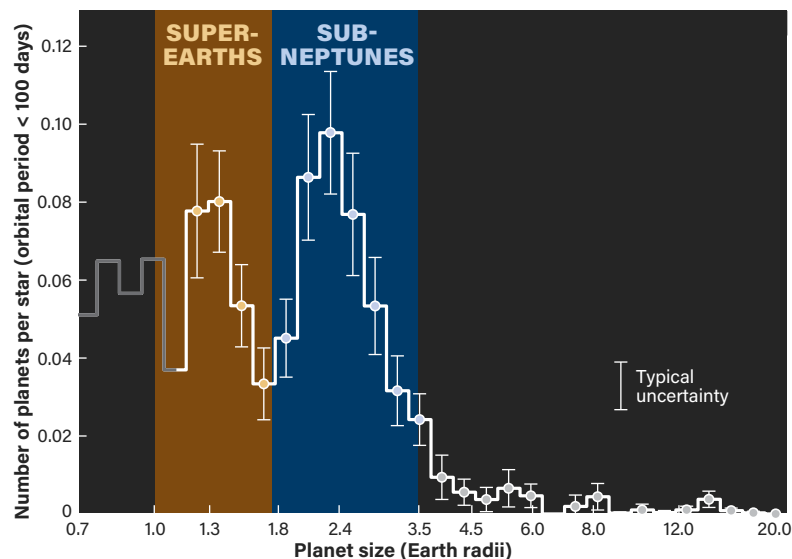
So, how do we discover them? Several methods exist.

All planets gravitationally interact with their star, as both star and planet orbit a common center of mass. Some planets have a large interaction — this happens when either the planet is massive, the distance between the two is small, or both. As it orbits, a planet pulls on its star,



↑ An artist's depiction shows 55 Cancri e, a super-Earth orbiting a star smaller and cooler than our Sun. However, it lies so close to its star that its surface is a searing 3,630 F (2,000 C). Astronomers have detected an atmosphere with hydrogen and helium — but no water. ESA/HUBBLE, M. KORNMESSER

A BIMODAL DISTRIBUTION



↑ Astronomers differentiate super-Earths and sub-Neptunes by the planet's size. Super-Earths are smaller, rocky planets more massive than Earth, which may host thin atmospheres. Sub-Neptunes are larger planets with rocky cores but a higher gaseous component (i.e., much thicker atmospheres), more like the ice giant Neptune. When extrasolar planets are plotted based on radius, a bimodal, or two-peaked, distribution appears, with a gap or valley separating super-Earths and sub-Neptunes. *ASTRONOMY: ROEN KELLY, AFTER FULTON ET AL. (2017)*

moving it slightly toward and away from Earth. Scientists see this “wobble” as a shift in the star’s light toward the blue or red end of the spectrum, respectively. Measuring this shift is known as the radial velocity method.

The radial velocity method is quite sensitive to hot Jupiters, massive planets orbiting close to their stars, because they induce a stronger wobble over a shorter period than do smaller planets farther away. Therefore, this method is biased toward hot Jupiters and less effective at finding super-Earths and sub-Neptunes — even “hot” (close-in) ones, which induce smaller signal amplitudes due to their smaller masses, Teske says.

Another method for finding planets is the transit method, in which astronomers measure the slight dimming of a star caused by a planet passing in front of it. Scientists can infer the size of the planet from the dip it causes in the light curve, or amount of starlight measured over time. This method is also most sensitive to larger planets close to their star because they block more starlight when they transit, causing a larger dip in brightness, and are also more likely to cross in front of their star from our point of view. The key is that the transit method requires that the planet and star be aligned along our line of sight so we can observe a transit. Because it is orientation-dependent, many

systems are not discoverable this way simply because the planets don’t line up between Earth and the star they orbit.

In cases where both techniques can be used together, astronomers can measure a planet’s size from transits and its mass from radial velocity. This allows us to calculate the planet’s density and make better guesses about its composition — which, in turn, might hint at its habitability.

PLANETARY INTRIGUE

Why are we so fascinated with super-Earths? After all, Earth is the only planet we know of with life, so why not focus on finding and studying other small planets?

For most of Earth’s 4.5-billion-year history, macroscopic life did not exist. Changes in the Sun and geological activity created massive shifts in the planet’s climate over time, transforming it into one friendly to developing life. But these changes were not inevitable. They happened by pure chance.

Super-Earths and sub-Neptunes are appealing because they might offer an even better chance of developing habitable conditions — and inhabitants. That’s because many orbit M (red) dwarfs, a class of star with a much longer lifespan than our Sun, which gives more time for conditions to change and life to arise. M dwarfs outnumber Sun-like stars by several orders of magnitude, and almost half of M dwarfs surveyed so far have super-Earths.

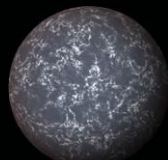
Not only do many M dwarfs host super-Earths, but about 50 percent have

IN THE MIDDLE



EARTH (ROCKY)

Radius: 3,960 miles (6,370 km)
Mass: 13.2×10^{24} pounds
 (5.97×10^{24} kg)
Density: 5.5 x water
Orbital distance: 1 AU
Orbital period: 365 days



LHS 3844 B (SUPER-EARTH)

Radius: 1.3 x Earth
Mass: 2.25 x Earth
Density: 6 x water
Orbital distance: 0.006 AU
Orbital period: 0.5 day



55 CANCRI E (SUPER-EARTH)

Radius: 1.9 x Earth
Mass: 8.1 x Earth
Density: 6.4 x water
Orbital distance: 0.015 AU
Orbital period: 0.7 day



GJ 1214 B (SUB-NEPTUNE)

Radius: 2.74 x Earth
Mass: 8.2 x Earth
Density: 2.2 x water
Orbital distance: 0.015 AU
Orbital period: 1.6 days

THE TRAPPIST-1 SYSTEM

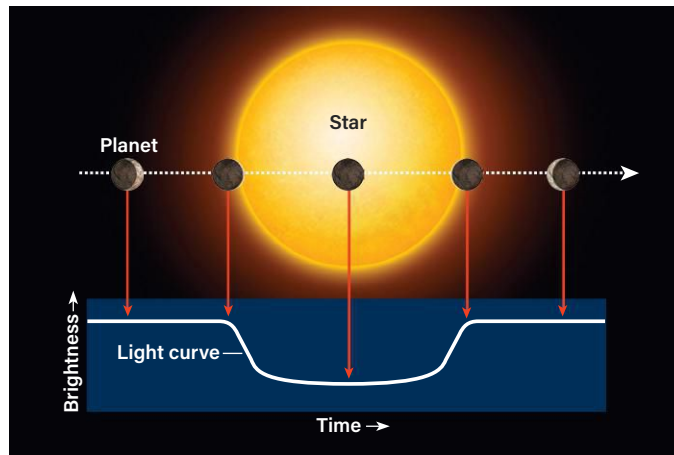
ONE OF THE MOST INTERESTING CANDIDATES for further study is TRAPPIST-1, a star system discovered in 2017 and located approximately 40 light-years away in the constellation Aquarius. Seven terrestrial planets orbit this star; several are super-Earths. JWST has just begun collecting data on these worlds, with recent measurements indicating that the innermost planet, TRAPPIST-1 b, does not have an atmosphere. Although that seems like a blow to the system's habitability, TRAPPIST-1 b in particular orbits the star too closely to be a viable candidate for hosting life. But three planets — TRAPPIST-1 e, f, and g — are in the star's habitable zone and astronomers are eagerly awaiting observations of them by JWST. —A.R.

super-Earths in their habitable zones, where temperatures are right for liquid water to exist on the surface. In our solar system, this is the region between the orbits of Venus and Mars. Given those statistics, astronomers consider the potential number of super-Earths in the habitable zone around stars in the Milky Way alone to be in the tens of billions. So, the search for super-Earths and sub-Neptunes is interesting to illustrate the way planetary systems form and evolve. But it's also important for its potential implications for the search for life beyond Earth.

A BREATH OF FRESH AIR

In addition to finding new worlds, characterizing them is vital to learn whether they host conditions favorable to life. The James Webb Space Telescope (JWST), the largest and most powerful space telescope ever built, is partly dedicated to this task. With a mirror six times larger in area than that of the Hubble Space Telescope (HST), its instruments operate in infrared wavelengths. In addition to three cameras, JWST also hosts several other instruments, including multiple spectrographs and coronagraphs. The spectrographs disperse light by wavelength, allowing us to

ANATOMY OF A TRANSIT



☞ Transits occur when a planet passes in front of its parent star from our point of view. As the planet transits, it blocks some of the star's light, causing a temporary dip in brightness that astronomers can use to identify planets, as well as determine their size and orbital period. NASA AMES

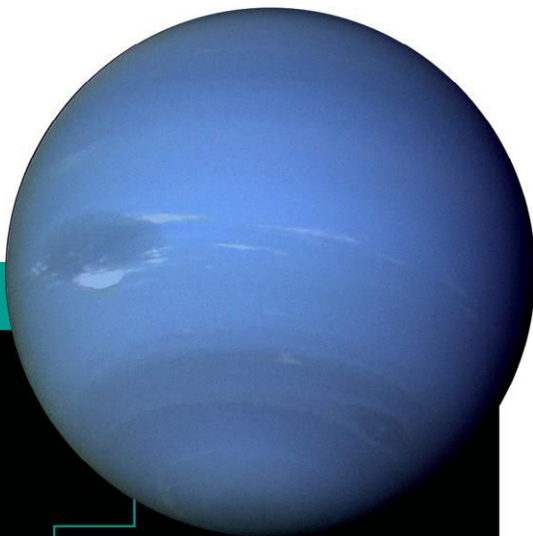
learn about the temperature and chemical composition of a planet. The coronagraphs block unwanted light from the host star so the planet's light can reach the sensors for direct imaging.

With these tools, JWST can provide detailed observations of exoplanetary atmospheres. Scientists can now search for signatures of water, methane, oxygen, and other molecules that offer a look into the atmospheres of super-Earths and sub-Neptunes. These observations are charting the path toward the search for biosignatures, Teske says, which are spectral signs of past or present life. Although this search is starting with JWST, she adds, it will likely require even larger ground- and space-based telescopes to inform us about the true nature of such planets' habitability.

Teske is part of a JWST program to better understand the atmospheres of super-Earth and sub-Neptune planets,

called Compositions of Mini-Planets for Atmospheric Statistical Study, or COMPASS. "We are thinking of and want it to be a helpful pointer for the community as to what observations might be most useful or distinguishing moving forward" as more planetary atmospheres are probed, she says. At first, the COMPASS team is focusing JWST on 12 planets, with the aim of determining the best wavelengths to probe for hallmarks of habitability, such as water in a planet's atmosphere.

"Before JWST, we had a few atmospheric observations of these types of small planets, mostly from HST, but not many," says Teske. "At this point, the basic question of, 'How does planet size correspond to the presence of an atmosphere?' isn't even well understood, so that's something we will try to tackle with our program." After that, she says, the team is eager to look at the diversity in atmospheric composition among these planets: "What are the relative abundances of molecules like water, methane, carbon dioxide, and what might that tell us about atmospheric processes or even interaction between the atmospheres and interiors of these planets?" she asks. "I'm particularly excited about that dimension — the

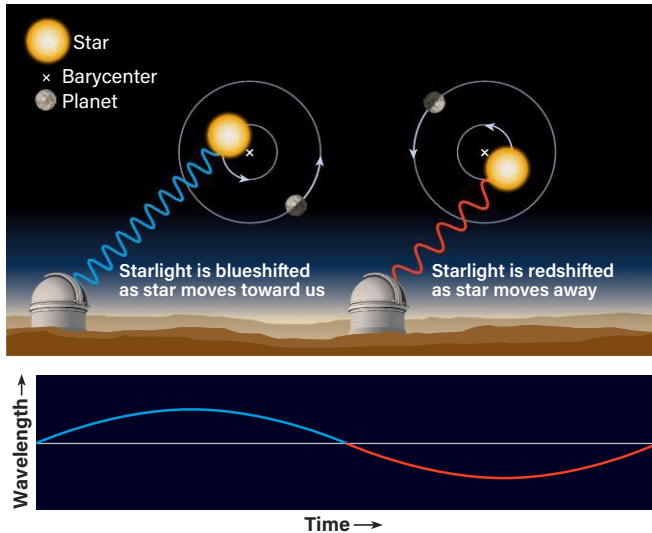


NEPTUNE (ICE GIANT)

Radius: 3.88 x Earth
Mass: 17.1 x Earth
Density: 1.6 x water
Orbital distance: 30.1 AU
Orbital period: 59,800 days

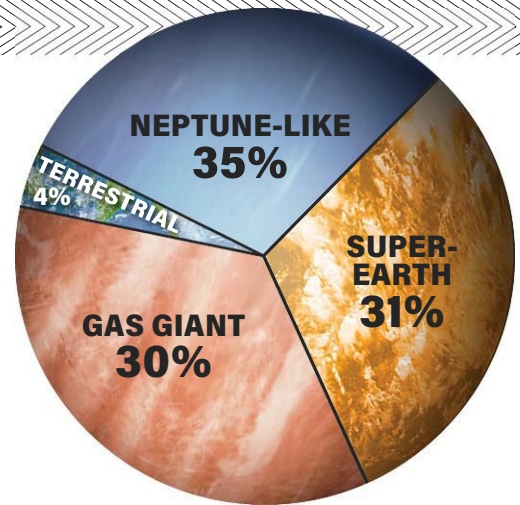
☞ Super-Earths and sub-Neptunes lie between Earth-sized and Neptune-sized planets. Astronomers can calculate the density of a planet, based on its physical size and mass, to determine whether it is likely more Earth-like (rocky with a thin atmosphere) or Neptune-like (rocky with a thick atmosphere). NASA, ESA, CSA, DANI PLAYER (STSCI)

WATCHING A STAR WOBBLE



⤴ A star-planet system orbits a common point called the barycenter. The radial velocity method watches for the telltale wobble as an orbiting planet tugs minutely on its sun, causing the star to move toward or away from Earth. This Doppler shifts the star's light slightly toward the blue or red end of the spectrum, revealing the planet's presence.

ASTRONOMY: ROEN KELLY



BY THE NUMBERS

⤴ Nearly one-third of known extrasolar planets are super-Earths whose properties lie between those of Earth and Neptune. Of the remaining planets, some 30 percent are gas giants like Jupiter or Saturn; roughly 35 percent are Uranus- or Neptune-like; and just 4 percent are rocky, terrestrial planets Earth-sized or smaller. *ASTRONOMY: ROEN KELLY, AFTER NASA/JPL-CALTECH*

atmospheres of small planets could be a new window into what is happening inside of them!”

The COMPASS program will also try to untangle how planets within the same system form. “We have four systems of sibling planets — two planets around the same star — in our program, so we can assess how similar their atmospheres are and, if they’re not similar, why that might be,” Teske says. Overall, she adds, the team hopes their results can be interpolated onto other super-Earths and sub-Neptunes, “hopefully starting to pick out trends between their atmospheric compositions and other parameters like bulk density or radiation from the host star.”

TWO NEW WORLDS

IN MAY THIS YEAR, astronomers using NASA’s Transiting Exoplanet Survey Satellite (TESS) announced the discovery of two super-Earth exoplanets in the habitable zone of their red dwarf parent star, TOI-2095, approximately 137 light-years from Earth. These planets, TOI-2095 b and TOI-2095 c, are slightly larger than Earth with masses four and seven times our planet’s, and orbital periods of 17.7 and 28.2 Earth days, respectively.

Although both planets orbit at a distance deemed technically habitable, young red dwarf stars typically emit intense radiation that precludes nearby planets maintaining an atmosphere. So scientists are particularly interested in following up on the find to determine whether these two exoplanets have atmospheres and thus might harbor environments supportive of life. —A.R.

CREATING WORLDS

Clearly, super-Earths aren’t hard to form. And the key to how these specific types of planets are created lies in understanding how all planets form.

Models show that the planets in our solar system grew by the gradual accumulation of material in the proto-planetary disk of dust and gas around the young Sun. Although the disk’s inner regions contained denser material, less of it existed close to the star, inside what astronomers call the ice line. This is the dividing line inside which temperatures are high enough to keep volatiles, such as water, in gaseous form. Beyond the ice line, cooler temperatures mean water and other compounds exist only as ice. So, the inner part of the disk produced smaller but denser, rocky planets: Mercury, Venus, Earth, and Mars. In the outer disk, material tended to accrete faster and produce more massive planets, whose gravity then pulled in nearby gas into thick atmospheres to form worlds such as Jupiter and Saturn. This is known as the core accretion hypothesis, the

most widely accepted model for how our solar system formed.

It seems that one reason we don’t have any super-Earths is the existence of Jupiter, whose orbit is highly responsible for our solar system’s dynamics. Scientists believe Jupiter may have migrated toward the inner part of the solar system before moving back out to its current position. This movement would have destabilized the orbit of any objects it neared, resulting in a lot of material spiraling in toward the Sun. Known as the Grand Tack hypothesis, this reasoning could explain why little material would have been left to form a super-Earth in the Sun’s habitable zone.

But what if we did have a super-Earth? Stephen Kane, an astronomer at the University of California, Riverside, ran computer simulations to probe the effects of such a planet on our solar system. His experiment dropped a fully formed super-Earth into the modern-day solar system and ran time forward for 10 million years to see what would occur.

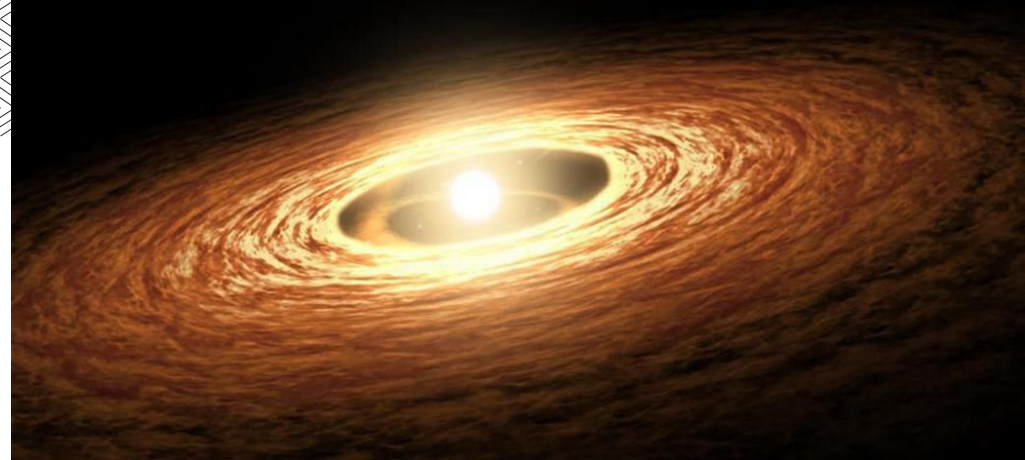
The results unequivocally showed that adding a super-Earth had devastating impacts on the orbital stability of the terrestrial planets. Although the gas giants Jupiter and Saturn were relatively undisturbed, changes in Jupiter’s orbit ejected some or all four rocky planets from the solar system; in some cases, even Uranus and Neptune were kicked out.

Kane found that reducing its mass and placing the super-Earth at 3 astronomical units from the Sun (1 astronomical unit is the average Earth-Sun distance) was the most stable option with the least influence on Jupiter's orbit. But outside of this exact scenario, Kane noted in a press release, "things would go poorly. Despite many astronomers having wished for this extra planet, it's a good thing we don't have it."

In other solar systems with suns like ours, Jupiter-like planets are rare and super-Earths are common. So, it seems that our solar system might not be a good model for developing a general theory of planetary system formation.

As scientists continued to discover exoplanets, they began noticing some trends: namely, that most super-Earths are rocky and when there are multiple super-Earths in a single system, they all have extremely similar features, such as size and mass. It's as if there is a blueprint or mold for super-Earth formation. But why?

Again, it seems the key lies with Jupiter. In 2020, astronomers Konstantin Batygin and Alessandro Morbidelli proposed a new formation theory for Jupiter's four largest moons, which are also similar in size to one another. Like the young Sun, Jupiter had a disk of material around it early in its life. The researchers showed that a balance in the forces pulling dust grains toward Jupiter and pushing them away formed a ring around the planet composed of grains with a certain size.



↑ Planets form from the disks of dust, gas, and ice that surround young stars, such as the one depicted here. Smaller, rocky worlds form closer to the star, where volatiles such as water are gaseous. In the outer regions of the disk, temperatures are colder and ices can condense. These are incorporated into gas and ice giants. NASA/JPL-CALTECH

These particles were the building blocks of the moons, which accumulated material until drag within the disk caused them to leave it and they stopped growing. This happened over and over again, creating multiple near-replicate bodies.

Since then, those same researchers have extended this theory to planet formation. They found that in protoplanetary disks, a similar ring forms where rocky material accumulates when forces are balanced. In systems with ample rocky material, their models show that as the rocky super-Earths reach a given mass, they move in toward the star and stop growing, and the process continues with the next planet. Their most recent results were published earlier this year in *Nature Astronomy*.

Although a nascent theory, this model has a lot of promise for explaining why we don't have super-Earths in our solar system. Solar system architecture appears

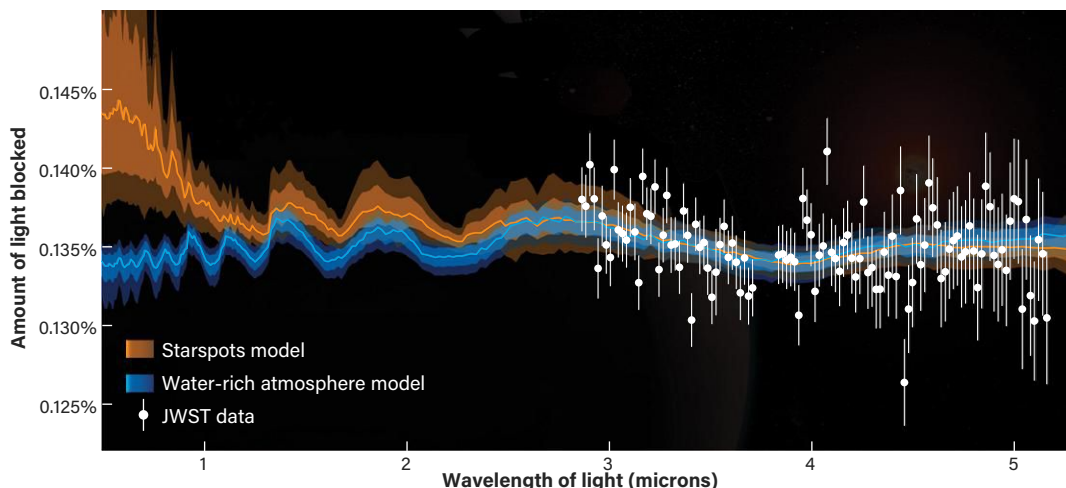
to be highly dependent on the amount of mass in that rocky ring. With little mass, we get a solar system that looks like our own terrestrial planets. A more massive ring spawns what seems to be homogeneous super-Earths.

THE SEARCH CONTINUES

The mystery of our solar system's missing super-Earths and sub-Neptunes is not yet solved. Studying these exoplanets is one of NASA's top priorities and JWST plays a pivotal role. This fascinating and challenging field of research is poised to reveal new insights into the formation and evolution of planets and solar systems, the conditions for habitability and life, and the diversity and complexity of the universe. ➤

April Russell is founder of *Take Space Consulting*, which focuses on making science more accessible.

EXOPLANET GJ 486 B TRANSMISSION SPECTRUM



➤ JWST observed the atmosphere of the super-Earth GJ 486 b as the planet passed in front of its star. Astronomers can use multiple models to explain the results. One (blue) indicates the planet may have water in its atmosphere, though a different model (orange) shows the observations may simply mean JWST is seeing starspots (cooler areas) on the planet's parent star. Because the models more clearly diverge at shorter wavelengths than those observed, future measurements with additional instruments will help differentiate between the two. SCIENCE:

SARAH E. MORAN (UNIVERSITY OF ARIZONA), KEVIN B. STEVENSON (APL), RYAN MACDONALD (UNIVERSITY OF MICHIGAN), JACOB A. LUSTIG-YAEGER (APL)



AUORAE

dazzle across the universe

Spectacular auroral emissions reveal just how interconnected stars, planets, and moons really are. **BY THEO NICITOPOLOUS**

IN THE SOLAR SYSTEM and beyond, aurorae brighten the skies of planets and moons. But aurorae are more than just a pretty light show. To scientists, they are nature's way of making visible the complex dynamics of magnetic fields and the invisible influence they wield throughout the universe.

Magnetic fields play an important role throughout the cosmos. The magnetic fields generated by stars, planets, and moons create emissions ranging from X-ray to radio wavelengths. Aurorae are a signpost for myriad interactions between matter and magnetic fields, which can drastically alter the nature of a planet or moon, including its habitability.

While satellites continuously survey Earth's magnetic field, we lack similar long-term, continuous coverage at our solar system's outermost planets — let alone exoplanets. For those distant bodies, aurorae are one of the few ways that scientists have of studying these crucial features.

Aurorae of Earth

The origin of most aurorae in our solar system lies with the solar wind that flows outward from the Sun. At Earth, those solar wind particles smack into and flow along the magnetic field lines of Earth's magnetosphere



▲ **GLOW FROM SPACE:** In 2022, an astronaut aboard the International Space Station captured an aurora shining over Earth. BOB HINES/NASA

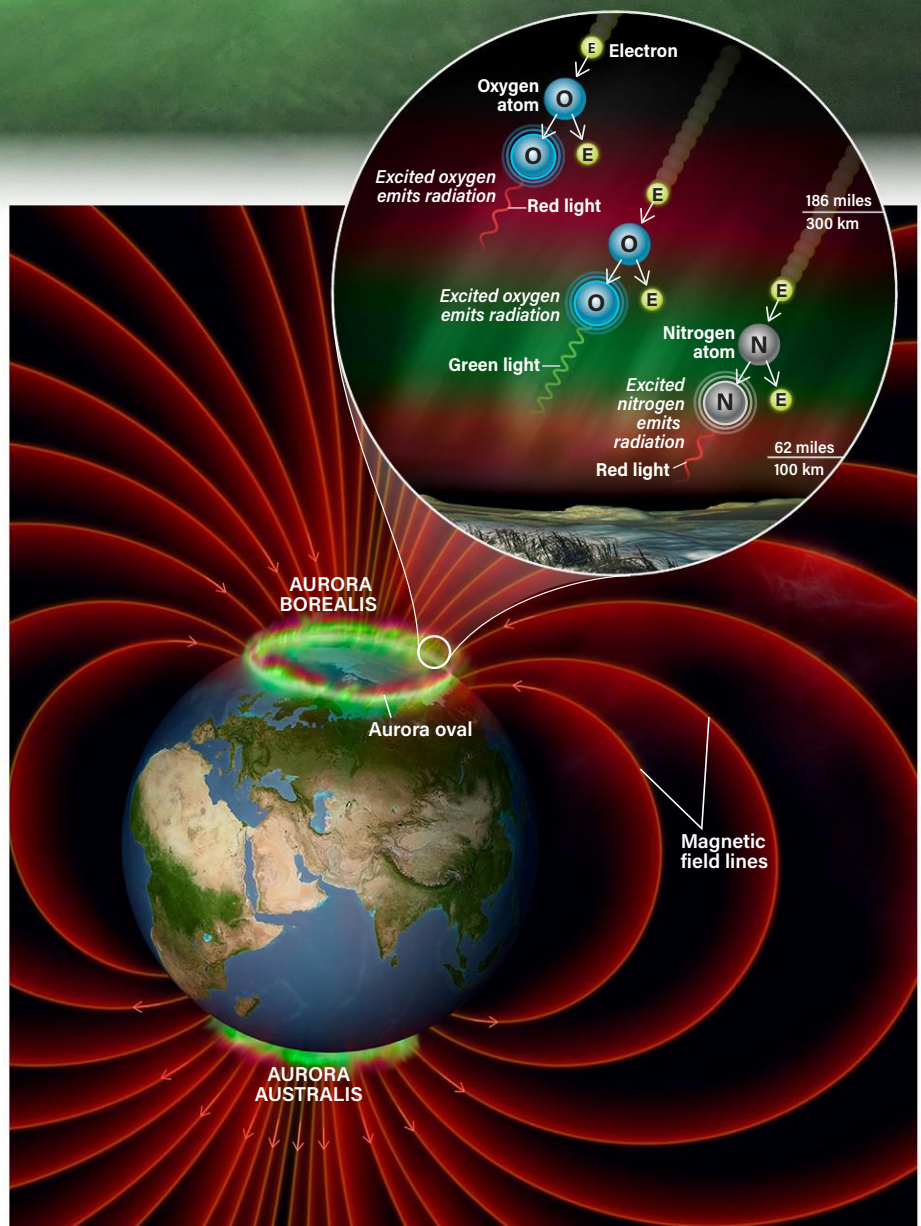
► **INCITING MECHANISM:** As charged particles slam into Earth's atmosphere, they excite atoms that then emit light when they settle back down to their ground state. The color of light emitted depends on which elements the molecules are made of. ASTRONOMY: ROEN KELLY

— the region where its magnetic field holds influence.

Pressure from the solar wind compresses the sunward-facing portion of the magnetosphere, while stretching the far end into a cometlike tail that extends into the shadowy space of Earth's nightside. That tail, called the magnetotail, plays a key role in aurorae.

"The magnetotail ... accelerates electrons from Earth's space and dumps them into the polar regions," says Eftyhia Zesta, a space physicist at NASA's Goddard Space Flight Center in Greenbelt, Maryland.

The electrons, in turn, collide with atmospheric gas molecules and impart energy, bumping them up to a higher-energy state. These excited atoms then



NORTHERN LIGHTS: This aurora borealis, seen in Canada's Northwest Territories, is green — the most common color — caused by oxygen molecules at low altitude.

CANADIAN SPACE AGENCY, UNIVERSITY OF CALGARY, ASTRONOMY NORTH

▼ FORMING AURORAE:

Earth's magnetic field creates a protective magnetosphere around the planet. Occasionally, the Sun emits a powerful coronal mass ejection and the magnetic field lines channel some of that energy into aurorae.

ASTRONOMY: ROEN KELLY

emit photons of visible light as they return to their original energy level. The well-known green aurorae, for example, happen when electrons collide with oxygen atoms between 62 and 186 miles (100 and 300 kilometers) above the surface. Rarer red aurorae are the result of electron-oxygen collisions higher up, and the purplish-pink-red fringes that sometimes appear at

the lower edges of aurorae are the work of nitrogen impacts.

Because the billions of intermittent flashes of light happen along magnetic field lines that are constantly moving, auroral bands appear to dance in the sky.

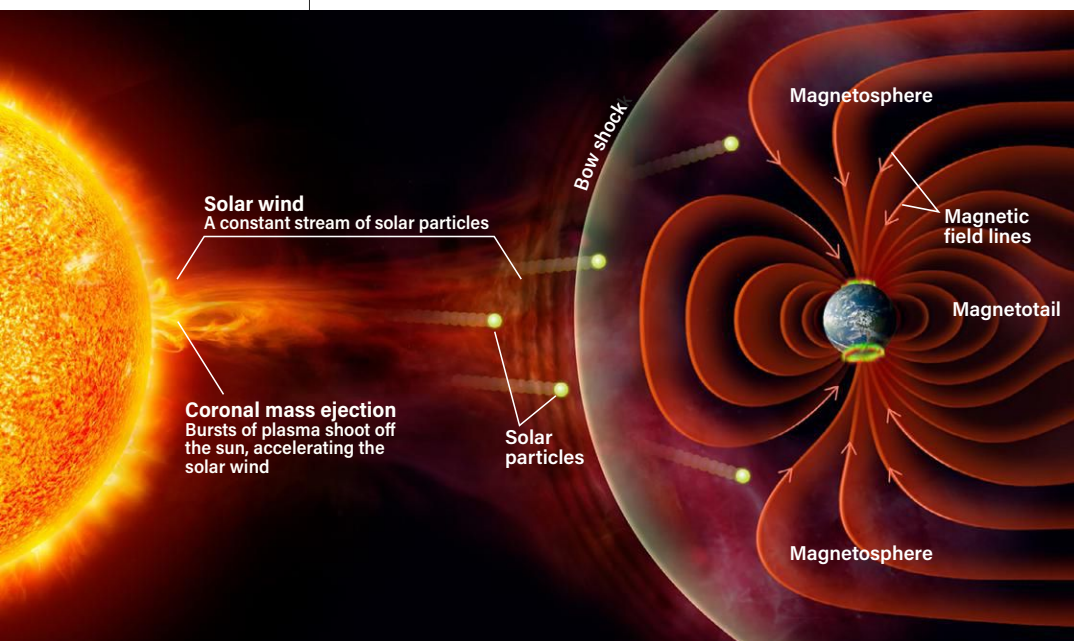
"When we look at aurorae, we are seeing the dynamics of how the solar wind's energy propagates through Earth's magnetosphere," says Zesta.

Aurorae are not just a night-time phenomenon, either: On Earth's dayside, protons in the magnetosphere collide with atmospheric hydrogen atoms and emit X-rays. "Aurorae are not always visible, but they are still a type of light," Zesta says.

Earth's aurorae share some similarities with others occurring on planets within our solar system. However, a planet's chemical makeup, location, and other unique qualities can produce radiant differences.

Across the solar system

Solar-wind-driven aurorae also happen on other planets that have magnetic fields. But to create such an aurora, the world must also have an atmosphere. This is why **Mercury**, despite possessing a weak magnetic field and experiencing the most intense solar wind in the solar system, doesn't have Earth-like aurorae. Instead, some of the solar wind that enters its magnetosphere is accelerated downward and collides with the surface, which ejects sodium and other elements that glow in sunlight, forming a shape similar to the



tail of a comet. “It’s not aurorae but it’s a similar process,” says Carl Schmidt, a space physicist at Boston University.

Venus, on the other hand, doesn’t have a magnetic field, but the solar wind’s particles collide directly with molecules like carbon dioxide and oxygen in the atmosphere to produce aurorae. Faint flashes of light have been detected in visible (the same green emissions seen on Earth’s nightside) and ultraviolet wavelengths.

Mars doesn’t have a global magnetic field today, either. But it used to, long ago, and rocks buried near the surface, mostly in the southern hemisphere, contain remnants of this magnetism. These rocks induce localized magnetic fields that extend thousands of kilometers above the surface. Like at Earth, electrons are accelerated within the mini-magnetic fields and collide with atmospheric atoms to produce aurorae. Emissions have been detected in ultraviolet and visible wavelengths. Particularly, the emission from electron-oxygen collisions suggests that green aurorae could be visible to future astronauts.

The solar wind also interacts directly with Mars’ atmosphere to produce aurorae, similar to the process at Venus. For example, Mars has dayside proton aurorae that occur when protons in the solar wind gain an electron from neutral hydrogen in the planet’s atmosphere, a process called charge exchange. These now-neutral solar wind atoms are able to travel into the atmosphere without being deflected, smacking into molecules there and releasing energy (light). There are also diffuse aurorae at midlatitudes that happen when energetic protons and electrons from solar flares impact the martian atmosphere.

Of all the aurorae in the solar system, none are more powerful than **Jupiter’s**. The planet’s

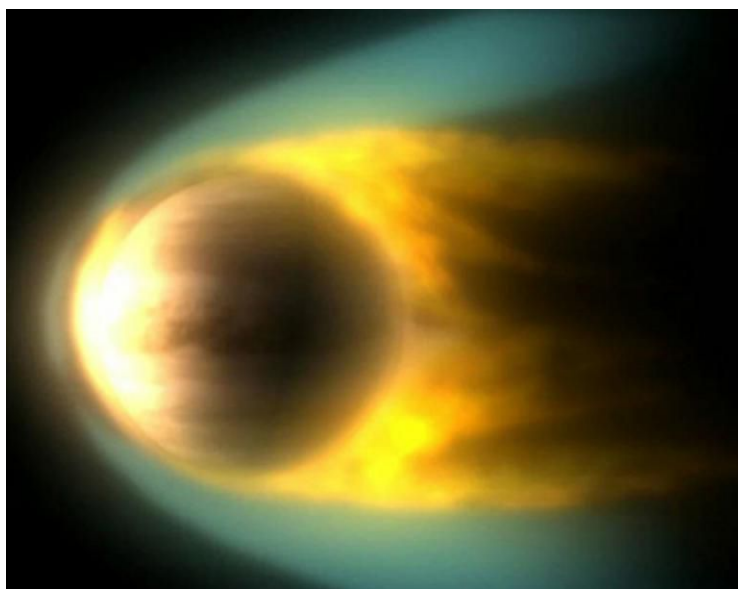
massive layer of metallic hydrogen in its outer core and fast rotation produce a highly dynamic and extensive magnetosphere that accelerates electrons deep into the atmosphere, where they collide with atoms such as hydrogen to produce northern and southern auroral lights with a shimmering red tone.

But there’s more going on at the solar system’s largest planet. “If you could turn off the solar wind, Earth would not have an aurora, but Jupiter would,” says Schmidt. That’s because many of the particles streaming along its magnetic field lines come from its volcanic moon Io, which orbits inside the gas giant’s magnetosphere.

Jupiter’s aurorae have been observed in ultraviolet, infrared, and visible light. The aurorae are so energetic that they could be one of the reasons the gas giant’s atmosphere is hotter than expected, based on the amount of sunlight it receives.

Jupiter’s magnetosphere also powers aurorae on its moons. At

Ganymede — the only known moon with a magnetic field — aurorae are driven by a process similar to Earth’s. However, Ganymede is also within Jupiter’s magnetosphere, so fluctuations in the planet’s magnetosphere can subsequently induce changes in Ganymede’s aurorae. Watching these changes — particularly the



▲ **MERCURY:**

Although not quite an aurora, Mercury’s sodium tail is the result of radiation pressure from solar wind causing sodium to escape in an anti-solar direction, forming a tail. Here, its brightness peaks on May 13, 2021.

ANDREA ALESSANDRINI

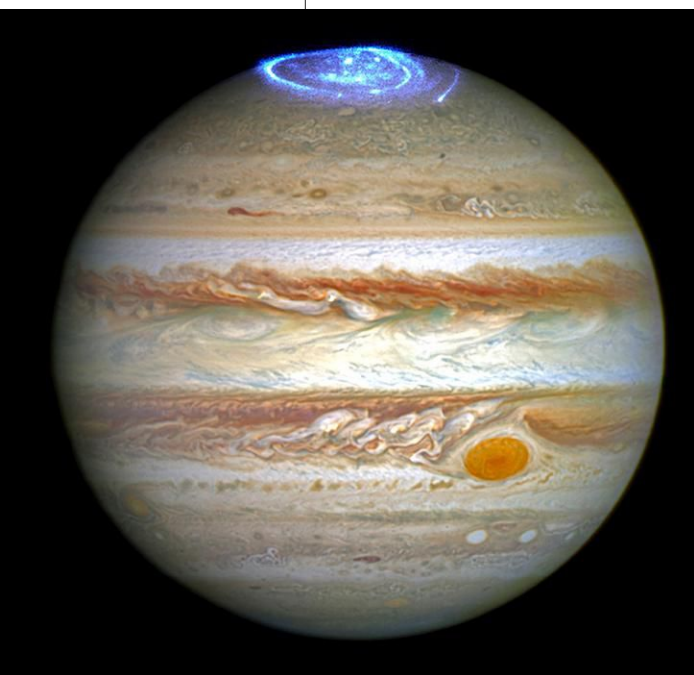
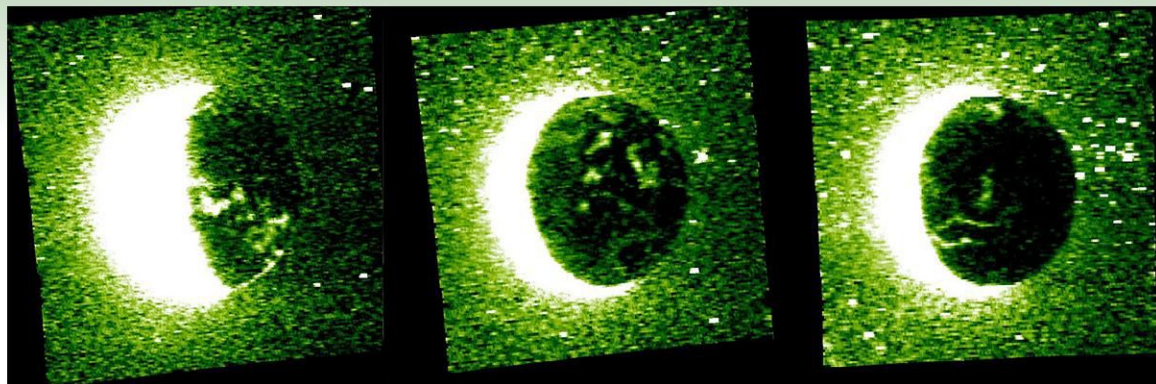
◀ **VENUS:**

Because Venus is closer to the Sun than Earth, the solar wind it experiences is much more intense, as seen in this artist’s rendition.

C. CARREAU/ESA

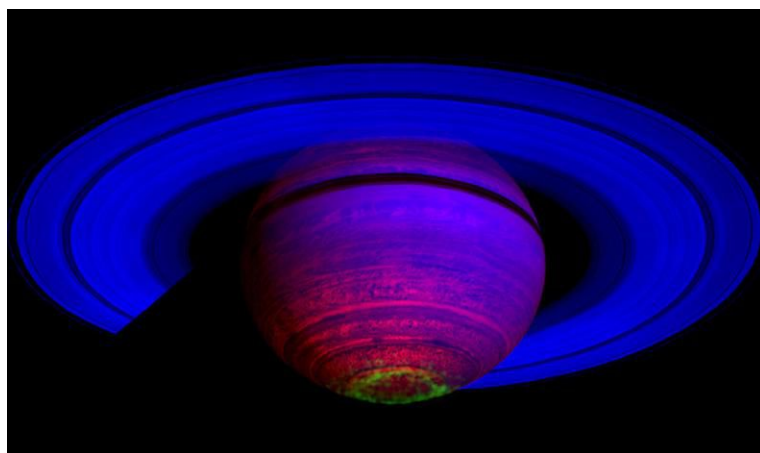
Venus doesn’t have a magnetic field, but the solar wind’s particles collide directly with molecules like carbon dioxide and oxygen in the atmosphere to produce aurorae.

► **MARS:** Three images taken by Emirates' Hope spacecraft feature Mars' glowing dayside to the left and the darker nightside at right. The nightside is speckled with auroral emission. UAE SPACE AGENCY



▲ **JUPITER:** The Hubble Space Telescope captured far-ultraviolet observations of strong aurorae at the poles of Jupiter, seen in this composite shot. NASA/ESA/J. NICHOLS (UNIVERSITY OF LEICESTER)

► **SATURN:** This false-color composite image, constructed from data obtained by NASA's Cassini spacecraft, shows the glow of aurorae at Saturn's southern pole. NASA/JPL/UNIVERSITY OF ARIZONA/UNIVERSITY OF LEICESTER



location and motion of the aurorae — has even provided compelling evidence for a subsurface saltwater ocean on the moon, affecting its internal magnetic field.

Aurorae have also been observed at **Io**, **Europa**, and **Callisto**, none of which have magnetic fields. In these cases, the gas giants' magnetospheres accelerate electrons and protons directly into their atmospheres, where they collide with gases like oxygen (Europa and Callisto) and sulfur dioxide and salts (Io) to produce myriad spectacular colors including red, green, and orange. The thin atmosphere on these moons causes the accelerated protons and electrons to expend less energy bouncing off the gases they do encounter, creating even brighter aurorae than Earth's.

Visible aurorae on the Galilean moons have been observed by spacecraft and even ground-based telescopes while the moons are in Jupiter's shadow, away from the Sun's bright light. When traveling through the shadow, the moons are nearly invisible and only the faint auroral light signals their presence, according to a paper co-authored by Schmidt this year.

Saturn's main auroral ovals appear over its polar regions. The size of Saturn's magnetosphere is somewhere between Earth's and Jupiter's. Scientists believe it is weaker than Jupiter's because Saturn has less metallic hydrogen.

Astronomers think Saturn's aurorae are generated by a combination of particles from the solar wind and hydrogen in the planet's atmosphere. Many of the particles in Saturn's atmosphere are also sourced from its moons — like Enceladus and Titan — and rings, pulled in by its magnetic field. These aurorae can last up to several days.

NASA's Cassini-Huygens spacecraft even spotted aurorae glowing 600 miles (1,000 km) above the planet's cloud tops. This type of display is called an auroral curtain, and Saturn's is the tallest in the solar system.

Compared to at Jupiter and Saturn, aurorae at **Uranus** and **Neptune** are not as well documented because of their distance from Earth and our limited up-close observations (a single flyby each with Voyager 2). But observations by the Hubble Space Telescope have confirmed ultraviolet aurorae on Uranus.

Like Jupiter and Saturn, most of the particles that slam into the ice giants' atmospheres are sourced from their moons and rings. For example, Voyager 2 detected ultraviolet aurorae on Neptune's nightside that showed signatures of atmospheric particles from its moon Triton.

Based on the limited data, scientists think aurorae on the ice giants differ greatly from their gas giant counterparts. Uranus,

for example, rotates on its side as it completes its 84-year trip around the Sun, and its magnetic field is further tilted at 59° relative to its spin axis. “This makes for complicated geometry unlike anywhere else,” says Schmidt. The result is a highly variable solar wind-magnetosphere interaction that can scatter auroral emission across the sky over much of the planet, rather than confining it to the poles.

In Neptune’s case, the planet itself isn’t tilted as much but its magnetic field is also offset from its rotational axis, by 47°. This likely leads to variable aurorae similar to those that have been seen at Uranus.

Looking beyond

The planets around our Sun aren’t the only places you’ll find aurorae. Astronomers have detected radio emissions from brown dwarfs — massive objects that span the gap between planets and stars — that are likely from aurorae. These bodies have very strong magnetic fields that could produce aurorae 100,000 times more intense than Jupiter’s. Researchers aren’t completely sure what causes aurorae in brown dwarfs, because they often lack solar winds to produce particles that would generate a light show. However, a planet orbiting within a brown dwarf’s magnetosphere could be a possible source of material.

Radio emissions that could be associated with aurorae have also been detected from red dwarf stars — for example, GJ 1151, YZ Ceti, and even the Sun’s closest neighbor, Proxima Centauri. This emission could be the result of electrons energized by the motion of a planet orbiting the star, similar to the aurorae generated on Jupiter by Io. If true, aurorae might be used to reveal exoplanets that are otherwise hidden.

And exoplanets likely also have auroral emissions, too, their

skies lighting up in spectacular colors, just as the worlds within our own solar system. “All the ingredients are expected to be there, so it would be quite shocking if exoplanets don’t have aurorae,” says Harish Vedantham, an astronomer at the Netherlands Institute for Radio Astronomy in Dwingeloo, Netherlands.

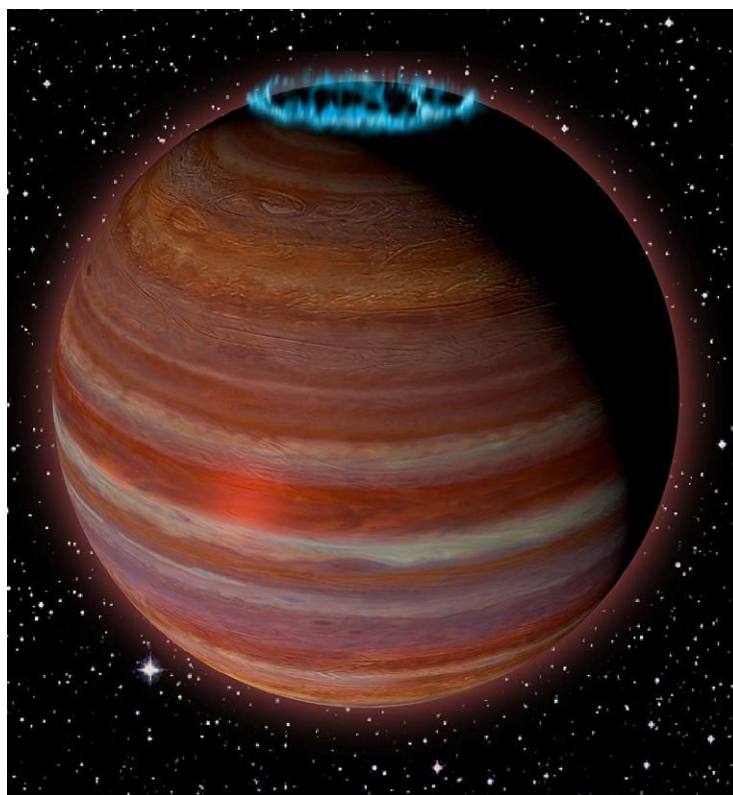
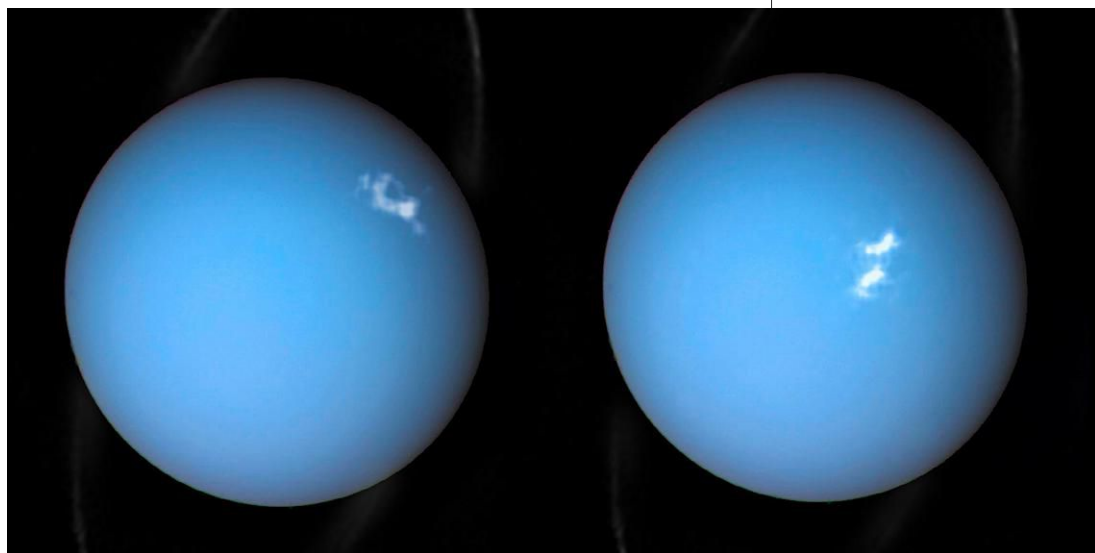
Because the magnetic fields of exoplanets are weaker than brown or red dwarfs, their auroral emissions are difficult to detect. If seen, though, aurorae could reveal whether an exoplanet has a magnetosphere

— an important factor for considering whether habitable conditions exist. For example, Earth’s magnetic field protects the planet from the solar wind and cosmic rays, making our planet a more life-friendly place.

“We have learned so much about the planets and moons in our solar system by studying aurorae and it’s exciting to do the same for extrasolar systems,” says Vedantham. 🌌

Theo Nicitopoulos is a freelance writer who covers Earth and space science news.

▼ **URANUS:** This composite combines observations of Uranus captured by both the Voyager 2 spacecraft and Hubble. Aurorae are seen as white patches in both photos, occurring in the tilted planet’s southern latitudes. NASA/ESA



◀ **BROWN DWARF:** SIMP J01365663+ 0933473, a brown dwarf, hosts a powerful magnetic field. It displays an aurora in this artist’s concept. CALTECH/CHUCK CARTER; NRAO/AUI/NSF

A TANGLED WEB OF DEBRIS

A star tore itself apart 340 years ago. The James Webb Space Telescope reveals the aftermath in all its glory. **BY RICHARD TALCOTT**

THE CALCIUM IN OUR BONES, the iron in our blood, and the oxygen we breathe all arose eons ago in the hearts of massive stars. These heavy elements ultimately found their way into our bodies after colossal explosions called supernovae ripped their suns apart and seeded our infant solar system with the debris.

No wonder, then, that astronomers would turn the power of the James Webb Space Telescope (JWST) on the remnants of these exploded stars. And there's hardly a better place to start than with one of the youngest and closest supernova remnants in the Milky Way Galaxy: Cassiopeia A (Cas A for short).

The light from Cas A's birth arrived at Earth some 340 years ago. It came from a massive star that almost certainly siphoned material from a smaller companion in a tight binary system. Over the course of a few million years, this massive sun burned through its nuclear fuel and was left with a core of iron. Because iron is the most stable element, the star's heart could no longer generate energy. The core then collapsed, triggering a shock wave that tore the rest of the star apart and scattered its outer layers into space.

The bulk of this debris continues to rush away from the explosion site at speeds of around 3,000 miles per second (5,000 kilometers per second). It forms a brightly glowing shell that currently spans some 10 light-years. At a distance of about 11,000 light-years, Cas A lies close enough that astronomers can probe it with all the weapons at their disposal — which now includes JWST's giant infrared eye.

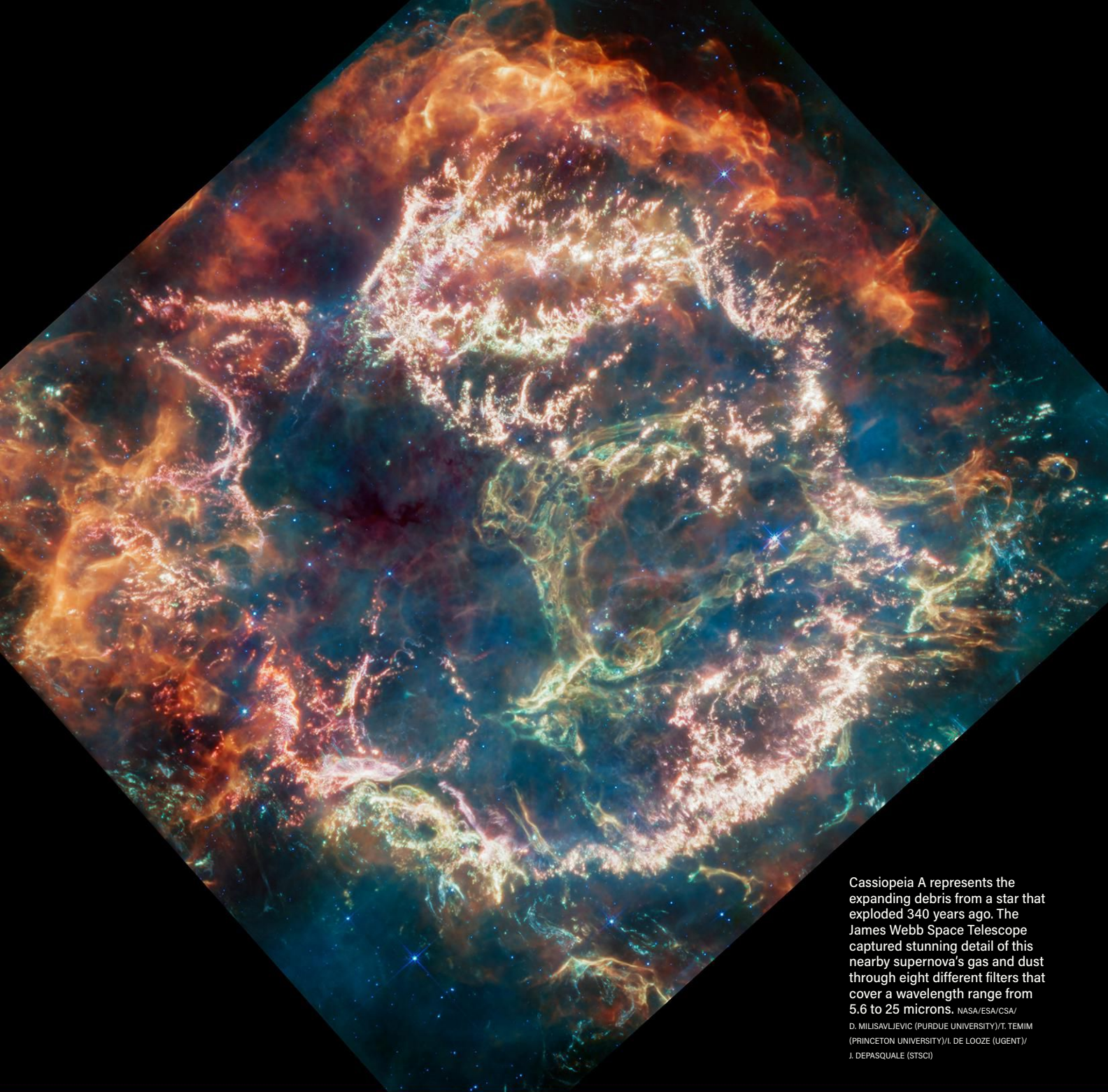
The space telescope's first inspection of Cas A reveals fine details in the remnant's structure. Warm dust glows in

shades of orange and red that appear most prominent in the image's north (top) and east (left). Much of this dust lies outside the remnant's 10-light-year-wide shell of explosive debris that shows up so well in visible light.

Dan Milisavljevic of Purdue University, who led the team that made these Cas A observations, says most of this material likely came from the progenitor star, carried away in a strong stellar wind that blew for tens of thousands of years before the explosion. The blast's shock wave then heated the dust. Smaller amounts may come from dust that formed in the supernova's aftermath or that already was present in the interstellar medium. Astronomers think most of the dust in the universe forms from the heavy elements supernovae shoot into space, and hope future JWST observations can shed more light on the creation of these building blocks of life and planets.



The Hubble Space Telescope imaged Cassiopeia A in visible light back in 2004. Stars appear more prominent here than in the JWST image because they don't emit much infrared light. NASA/ESA/THE HUBBLE HERITAGE TEAM (STSCI/AURA)



Cassiopeia A represents the expanding debris from a star that exploded 340 years ago. The James Webb Space Telescope captured stunning detail of this nearby supernova's gas and dust through eight different filters that cover a wavelength range from 5.6 to 25 microns. NASA/ESA/CSA/D. MILISAVLJEVIC (PURDUE UNIVERSITY)/T. TEMIM (PRINCETON UNIVERSITY)/L. DE LOOZE (UGENT)/J. DEPASQUALE (STSCI)

Inside this dusty outer shell lie scores of wispy tendrils and thicker clumps representing the supernova's ejecta. The infrared light JWST sees comes from heavy elements spread throughout the remnant's interior, including oxygen, sulfur, neon, and argon.

Perhaps the remnant's most surprising detail is a bright green loop just right of center. Milisavljevic says, "This area of

the remnant represents one of the most exciting — and most complex to understand — discoveries made with the Webb data. I'm convinced that a proper [interpretation of this structure] will serve as a Rosetta Stone in our understanding of the progenitor star and explosion dynamics."

The astronomers aren't done targeting Cas A with JWST. Milisavljevic says their next task is to perform a spectroscopic

survey of the remnant at hundreds of locations to pin down its composition. Then they'll grab another round of images to watch the ejecta move and create a time-lapse animation. »

Contributing Editor **Richard Talcott** has been captivated by exploding stars ever since Supernova 1987A rocked the Large Magellanic Cloud in February 1987.

SKY THIS MONTH

 Visible to the naked eye
 Visible with binoculars
 Visible with a telescope

THE SOLAR SYSTEM'S CHANGING LANDSCAPE AS IT APPEARS IN EARTH'S SKY.

BY MARTIN RATCLIFFE AND ALISTER LING

OCTOBER 2023

Prepare for annularity



During an annular solar eclipse, the Moon appears too small to completely cover the Sun. This shot of the Oct. 3, 2005, eclipse shows prominences at the Sun's edge.

STEFAN SEIP - WWW.PHOTOMEETING.DE

by the dark Cassini Division. The diaphanous inner C ring is lighter and partly transparent.

Saturn's brightest moon is magnitude 8.5 Titan. It is north of the planet Oct. 9/10 and 25/26, and south Oct. 1/2 and 17/18. Some evenings, a star lies close to the planet, such as a 10th-magnitude field star Sept. 30/Oct. 1. It can be easily mistaken for a moon.

You will find three 10th-magnitude moons — Tethys, Dione, and Rhea — orbiting closer in than Titan. Their orbits lie in the plane of the rings and as the angle shrinks,

transits of the planet's disk occur. Tethys does this twice, once on Oct. 15/16 and again on the 17th. Tethys begins transiting shortly after 1:00 A.M. EDT on the 16th (still the 15th in western time zones), taking just over 70 minutes to cross the disk. Its tiny shadow follows within five minutes of the transit start, though you'll need exceptional seeing conditions to view it. The sequence repeats Oct. 17 beginning around 10:20 P.M. EDT, with Tethys taking about the same amount of time to cross the disk. Note that these are approximate times; begin observing 15 to 20 minutes early. Recording video is better than visually trying to track the event.

Enceladus shines at 12th magnitude close to the edge of the disk. As the rings close over the next few years, this moon will become easier to spot as the glare from the rings diminishes.

Iapetus is less than 1' east of Saturn the morning of Oct. 1. It lies between Titan and Dione. The 10th-magnitude field star is



An annular eclipse of the Sun on Oct. 14 is the big event this month, with most of the U.S. seeing a partial eclipse. Saturn is stunning in the evenings, while Jupiter is nearing its best for the year, visible all night. And it's a good time to track down Uranus and Neptune in binoculars. Venus dazzles in the morning sky, rising about four hours before the Sun. The second week of October is also a great time to view the zodiacal light.

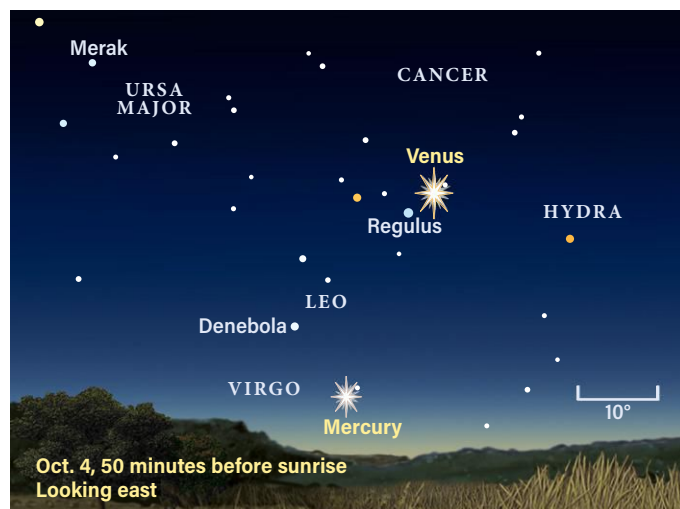
Saturn is well placed all evening for observation with a telescope. It starts out at magnitude 0.5 and dips by 0.1 magnitude during October. The planet's location in southwestern Aquarius adds luster to this dimly lit region of sky.

The ringed planet stands high in the south well before midnight. It sets by 4 A.M. on Oct. 1 and two hours earlier on Halloween. You'll find Saturn 5° northeast of a waxing gibbous Moon overnight on Oct. 23/24.

Small telescopes readily show off the rings. Larger scopes reveal little more of the planet visually; details on the 18"-wide disk are best captured by using high-speed video and stacking the best frames.

Saturn's ring system remains more than 41" wide from its distance of over 9 astronomical units (837 million miles; 1 astronomical unit, or AU, is the average Earth-Sun distance). The current ring tilt is about 10°. The outer A ring is separated from the brighter B ring

Brief appearance



Mercury is briefly visible in the morning sky early this month, though a clear eastern horizon is needed to spot it. Venus will blaze all month, officially reaching dichotomy on the 23rd. ALL ILLUSTRATIONS: ASTRONOMY: ROEN KELLY

OBSERVING HIGHLIGHT

An **ANNULAR SOLAR ECLIPSE** occurs Oct. 14, visible from parts of North, Central, and South America.



a mere 15" from Iapetus, making this a good night to spot the moon, glowing near 11th magnitude. Iapetus is racing toward eastern elongation on the 18th, dimming to 12th magnitude.

Neptune is visible all night in Pisces. It's beyond the naked-eye limit, requiring binoculars or a telescope to spy. At magnitude 7.7, the distant world's brilliance is similar to many other objects', so it's best to use brighter stars as a guide.

Magnitude 5.5 20 Piscium serves this purpose well. It's westernmost in a line of three stars of similar brightness south of the Circlet of Pisces. Neptune stands 33' west of 20 Psc on Oct. 1 and moves west each night. In mid-October, Neptune is very close to a magnitude 7.3 star, arriving just 6' due north of it on the 15th.

Through a telescope, Neptune spans 2" and glows bluish. It's only a couple of weeks past opposition at the start of October, making this a great time to view the planet.

Jupiter is one month from opposition as October opens and rises just after 8 P.M. local daylight time. It's gaining in diameter and brightness; by month's end it's reached a span of 49" and a magnitude of -2.9, its most brilliant of the year.

Jupiter is located in southern Aries. On the 1st,
— Continued on page 34

RIISING MOON | One glorious sight after another

THE WAXING CRESCENT MOON rides low in the autumnal evening sky yet sports a magnificent array of wonders along the light-dark terminator that make it worthwhile to watch each night.

On the 21st, the rugged lunar Apennines thrust diagonally into the sunlit domain near the lunar equator. Lying to their north along the terminator are two young craters — Autolycus and Aristillus — sticking up proudly above the lower plains. They formed a couple of billion years ago near the end of the last major lunar bombardment. The low Sun angle highlights the rugged apron of debris that splattered around each circular formation, while their steep, high walls prevent this light from reaching much of the floors. Stay for an hour on nearby fabulous Archimedes and watch the long shadows stretching into the terminator retreat as the rotation of the Moon causes the Sun to rise.

Consider the characteristics of these "youthful" craters. The larger impactor that created Aristillus was able to excavate a lot more material — there are many more streaks and ridges pointing radially away from this crater than Autolycus. Also compare the rims and aprons to those of the large, round craters Hipparchus and Albategnius south of the equator. Evidence of the latter's greater age comes from their degraded features, the result of incessant pounding from smaller impacts over time. Their



Autolycus and Aristillus 🔭



Peer along the terminator separating lunar night and day late on Oct. 21st to watch as several craters begin to appear.

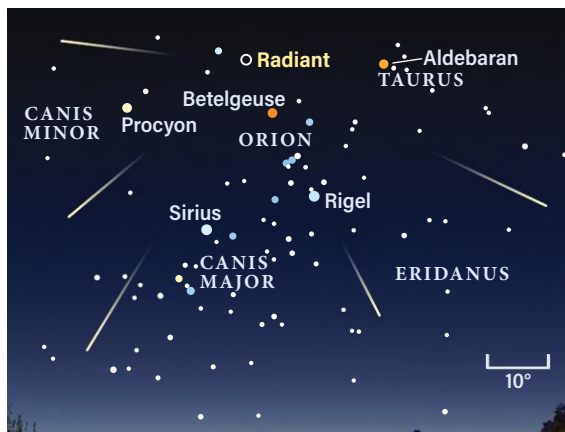
CONSOLIDATED LUNAR ATLAS/UA/LPL. INSET: NASA/GSFC/ASU

central peaks are lower, their walls are rounded and pockmarked with dozens of craterlets, and their aprons have been smoothed out.

Return on the 22nd to see how the higher Sun angle begins to conceal the aprons' roughness. You may also notice the appearance of the Straight Wall located in the southern third of the Moon.

METEOR WATCH | What Halley leaves behind

Orionid meteor shower 👁



ORIONID METEORS

Active dates: Oct. 2–Nov. 7

Peak: Oct. 22

Moon at peak: Waxing gibbous

Maximum rate at peak:

20 meteors/hour

Oct. 22, 5 A.M.
Looking south

The Orionids' radiant in northeastern Orion is highest in the hours before dawn.

THE PEAK OF THE ORIONID meteor shower coincides nicely with a First Quarter Moon this year. After the September lull, observers look forward to the Orionids in part because they are produced from debris shed during historic passes of the famous Halley's Comet. The Orionids could reach a zenithal hourly rate of 20 to 30 meteors per hour overnight on Oct. 21/22, the night of maximum, corresponding to an observable rate of 15 to 20 per hour between 2 A.M. and dawn as the radiant in northeastern Orion rises higher in the sky.

The shower is active from Oct. 2 through Nov. 7, and rates away from the maximum are much lower. The radiant rises by 11 P.M. local daylight time. As with all meteor showers, the best observing time is in the early morning, when you are on the leading side of Earth and heading directly into the meteor stream.

STAR DOME

HOW TO USE THIS MAP

This map portrays the sky as seen near 35° north latitude. Located inside the border are the cardinal directions and their intermediate points. To find stars, hold the map overhead and orient it so one of the labels matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

The all-sky map shows how the sky looks at:

10 P.M. October 1
9 P.M. October 15
8 P.M. October 31

Planets are shown at midmonth

MAP SYMBOLS

- Open cluster
- ⊕ Globular cluster
- Diffuse nebula
- ⊕ Planetary nebula
- Galaxy

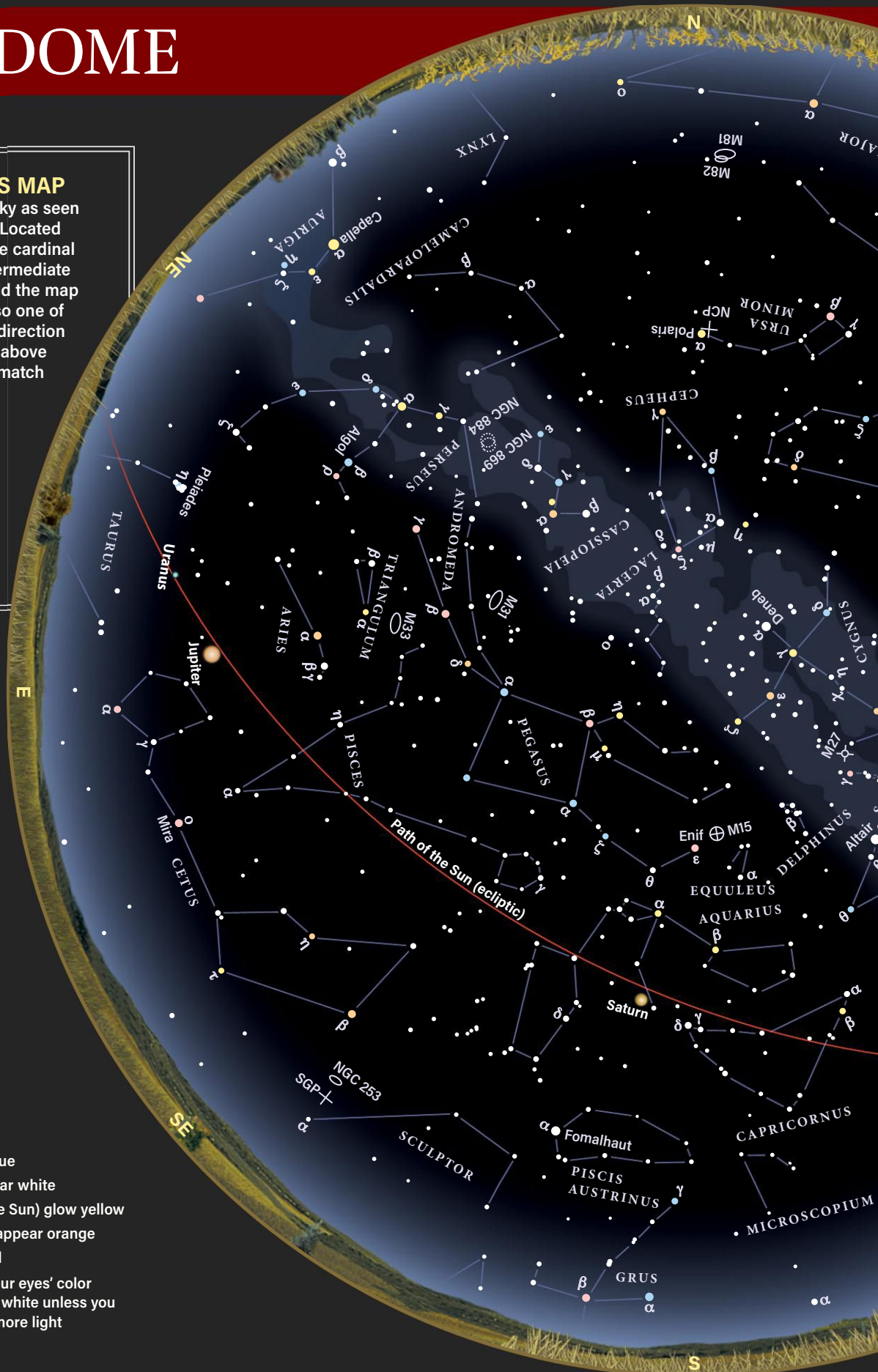
STAR MAGNITUDES

- Sirius
- 0.0 ● 3.0
- 1.0 ● 4.0
- 2.0 ● 5.0

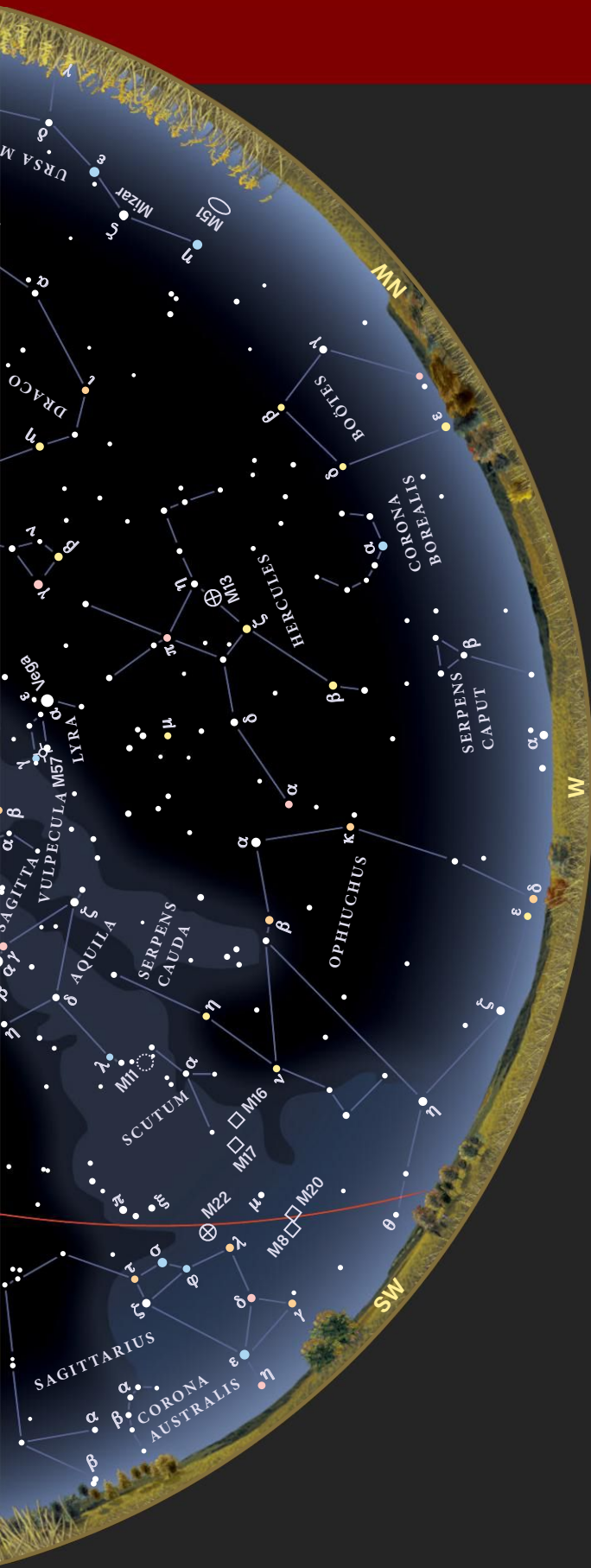
STAR COLORS

A star's color depends on its surface temperature.

- The hottest stars shine blue
- Slightly cooler stars appear white
- Intermediate stars (like the Sun) glow yellow
- Lower-temperature stars appear orange
- The coolest stars glow red
- Fainter stars can't excite our eyes' color receptors, so they appear white unless you use optical aid to gather more light



BEGINNERS: WATCH A VIDEO ABOUT HOW TO READ A STAR CHART AT www.Astronomy.com/starchart.



OCTOBER 2023

SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.
 1	 2	 3	 4	 5	 6	 7
 8	 9	 10	 11	 12	 13	 14
 15	 16	 17	 18	 19	 20	 21
 22	 23	 24	 25	 26	 27	 28
 29	 30	 31				

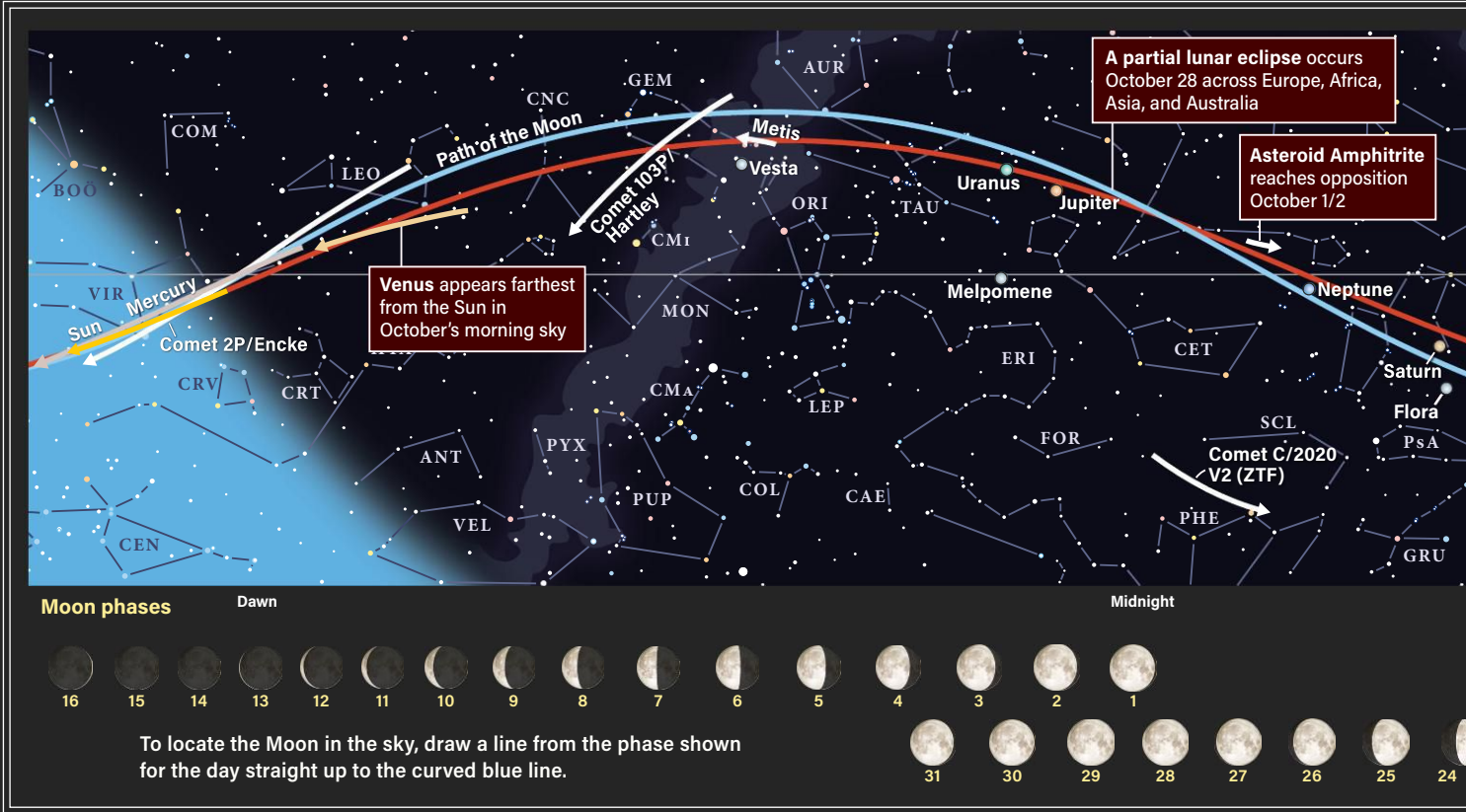
ILLUSTRATIONS BY ASTRONOMY: ROEN KELLY

Note: Moon phases in the calendar vary in size due to the distance from Earth and are shown at 0h Universal Time.

CALENDAR OF EVENTS

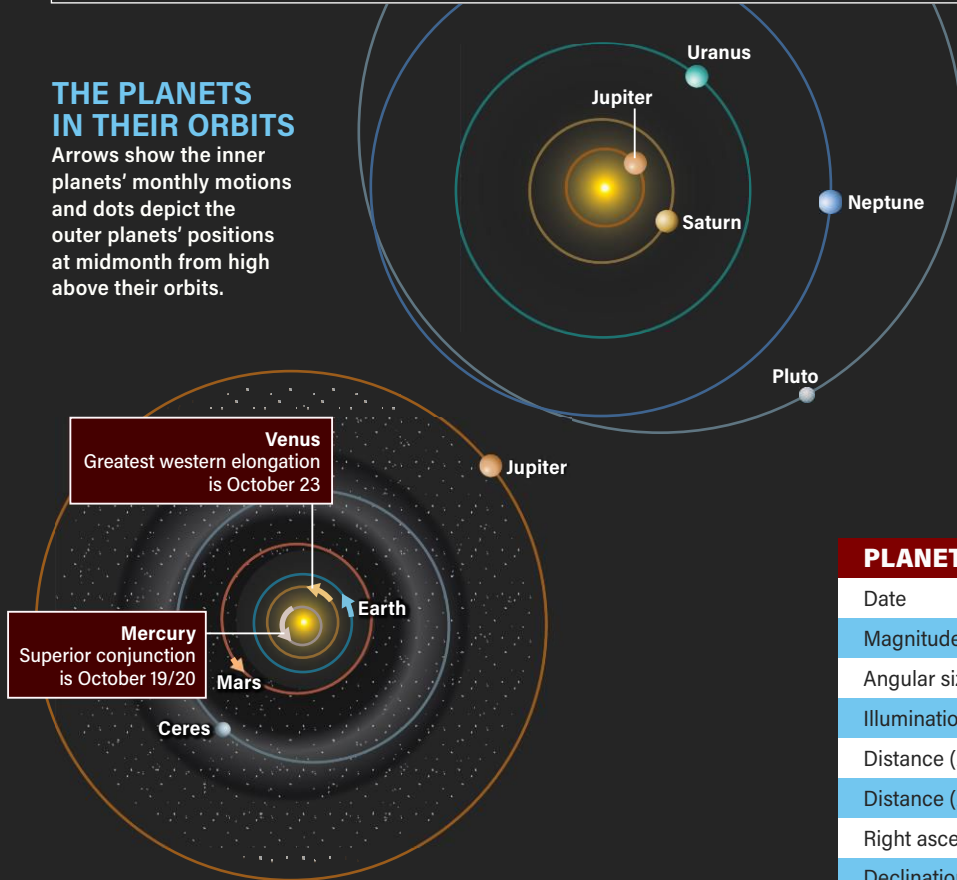
- Asteroid Pallas is in conjunction with the Sun, noon EDT
The Moon passes 3° north of Jupiter, 11 P.M. EDT
- Asteroid Amphitrite is at opposition, 3 A.M. EDT
The Moon passes 3° north of Uranus, 1 P.M. EDT
-  Last Quarter Moon occurs at 9:48 A.M. EDT
- The Moon is at apogee (251,920 miles from Earth), 11:42 P.M. EDT
- Venus passes 2° south of Regulus, 1 A.M. EDT
The Moon passes 6° north of Venus, 6 A.M. EDT
Pluto is stationary, 8 P.M. EDT
-  New Moon occurs at 1:55 P.M. EDT; annular solar eclipse
- The Moon passes 0.8° north of Antares, 10 A.M. EDT
- Mercury is in superior conjunction, 2 A.M. EDT
- Orionid meteor shower peaks
 First Quarter Moon occurs at 11:29 P.M. EDT
- Venus is at greatest western elongation (46°), 7 P.M. EDT
- The Moon passes 3° south of Saturn, 4 A.M. EDT
- The Moon passes 1.5° south of Neptune, 9 P.M. EDT
The Moon is at perigee (226,721 miles from Earth), 11:02 P.M. EDT
-  Full Moon occurs at 4:24 P.M. EDT; partial lunar eclipse
- The Moon passes 3° north of Jupiter, 4 A.M. EDT
The Moon passes 3° north of Uranus, 10 P.M. EDT

PATHS OF THE PLANETS



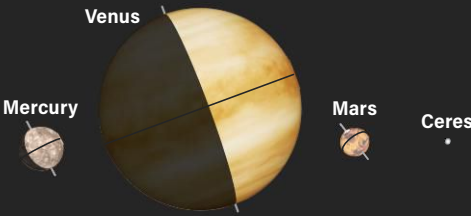
THE PLANETS IN THEIR ORBITS

Arrows show the inner planets' monthly motions and dots depict the outer planets' positions at midmonth from high above their orbits.



THE PLANETS IN THE SKY

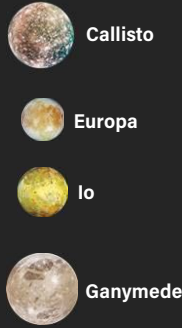
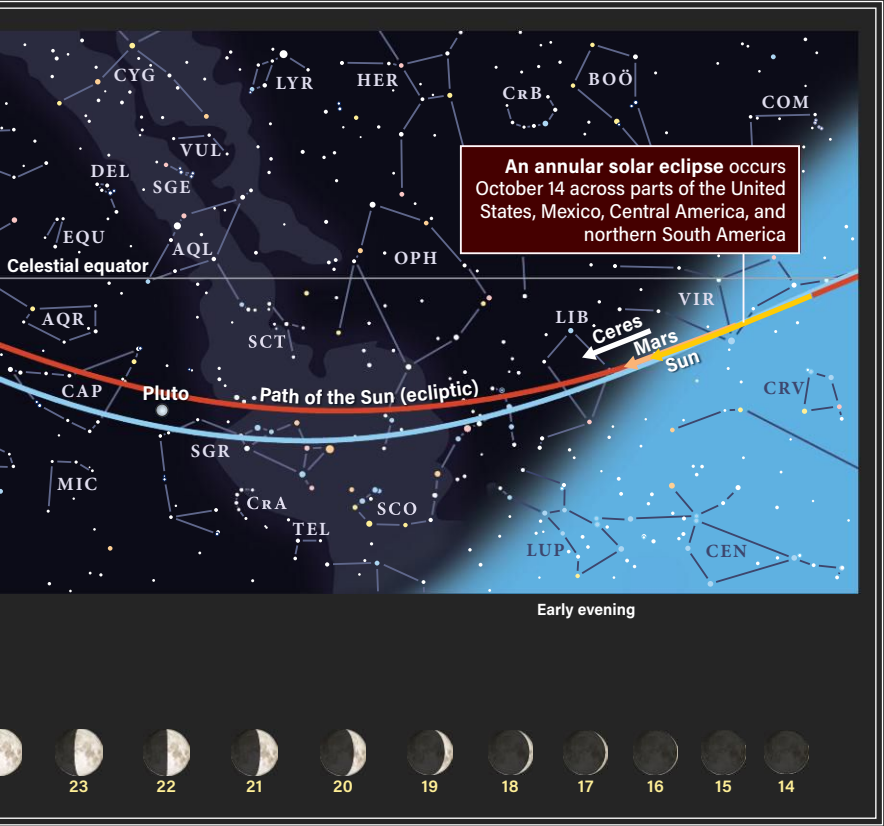
These illustrations show the size, phase, and orientation of each planet and the two brightest dwarf planets at 0h UT for the dates in the data table at bottom. South is at the top to match the view through a telescope.



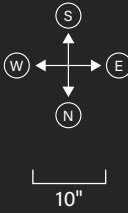
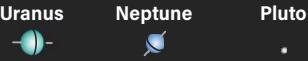
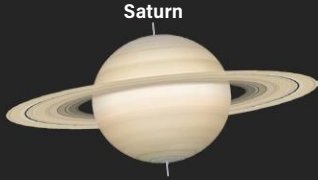
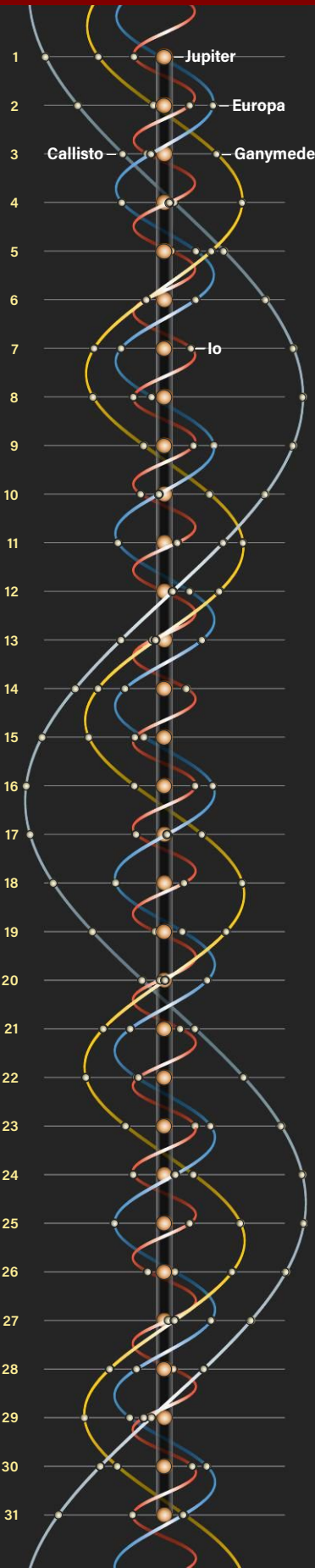
PLANETS	MERCURY	VENUS
Date	Oct. 1	Oct. 15
Magnitude	-1.1	-4.6
Angular size	5.7"	26.6"
Illumination	81%	46%
Distance (AU) from Earth	1.173	0.627
Distance (AU) from Sun	0.323	0.722
Right ascension (2000.0)	11h36.5m	10h25.5m
Declination (2000.0)	4°33'	8°39'

This map unfolds the entire night sky from sunset (at right) until sunrise (at left). Arrows and colored dots show motions and locations of solar system objects during the month.

OCTOBER 2023



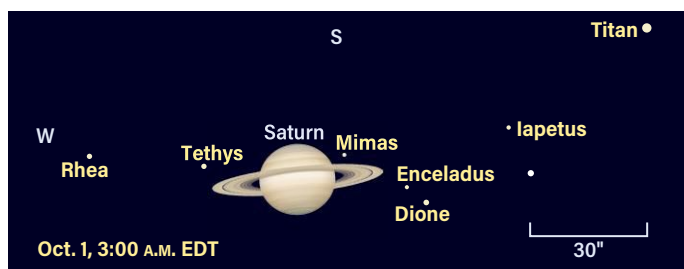
JUPITER'S MOONS
Dots display positions of Galilean satellites at 4 A.M. EDT on the date shown. South is at the top to match the view through a telescope.



MARS	CERES	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
Oct. 15	Oct. 15	Oct. 15	Oct. 15	Oct. 15	Oct. 15	Oct. 15
1.6	8.9	-2.9	0.6	5.7	7.7	15.2
3.7"	0.4"	48.9"	18.3"	3.8"	2.4"	0.1"
100%	100%	100%	100%	100%	100%	100%
2.549	3.601	4.031	9.095	18.763	29.005	34.743
1.579	2.697	4.972	9.760	19.626	29.906	34.870
13h58.1m	14h43.4m	2h42.7m	22h12.9m	3h18.2m	23h44.6m	20h00.9m
-11°49'	-11°34'	14°17'	-12°56'	17°55'	-3°03'	-23°20'

SKY THIS MONTH — Continued from page 29

Stellar signpost 🔭



On Oct. 1, a 10th-magnitude field star (unlabeled point) guides your eye to 11th-magnitude Iapetus, sitting between Titan and Dione east of Saturn's rings.

the planet lies 3° south of a waning gibbous Moon.

Jupiter's disk is packed with detail when seen through a telescope, though newcomers attempting their first view will find much of it subtle. Patient viewing aids in spotting fine details. The twin equatorial belts are the darkest features, along with the occasionally visible Great Red Spot.

The Galilean moons orbit every two to 17 days. In the runup to opposition, transits of the moons are preceded by their shadows with decreasing time separation. By early next month, both shadow and moon transit almost simultaneously. After opposition, the moon leads, followed by its shadow.

Check out the transit of Io Oct. 5, beginning with the moon's shadow at 9:50 P.M. EDT, just as Ganymede is skimming the planet's south pole. Io slips onto the disk shortly after 10:30 P.M. EDT. The shadow leaves the disk at midnight EDT, while Io follows 41 minutes later. On the 28th, Io's shadow leads the moon by only nine minutes, starting at 10:02 P.M. EDT. Other transits with intermediate timing occur Oct. 12/13 and 21.

Ganymede performs a fine transit Oct. 12, prior to Io's event the same evening. Starting at 9:56 P.M. EDT (not visible from Mountain and Pacific time

zones), its huge black shadow crosses the planet's southern polar region. Io's shadow appears at 11:44 P.M. EDT, just as Ganymede's shadow is leaving the southwestern limb. Io's transit starts at 12:18 A.M. EDT on the 13th (Oct. 12 in all other U.S. time zones), followed 20 minutes later by Ganymede.

Europa transits the evenings of Oct. 2/3, 9/10, and 16/17, and early on the 24th. Each event starts progressively later in the

night or early morning. Due to the moons' inclined orbital plane relative to our line of sight, Callisto passes north or south of the disk this month.

Uranus stands about 9° southwest of the Pleiades (M45) and 9° northeast of Jupiter. Scan the sky between Jupiter and M45 to find a small grouping of 5th-magnitude stars including Tau (τ) Arietis. Uranus is just over 3° south of this star. The planet glows at magnitude 5.7. Its bluish hue should stand out against the rest of the starfield.

Uranus moves westward as it approaches next month's opposition, passing between a pair of widely spaced 7th-magnitude stars from the 16th to the 18th. By month's end, Uranus lies 18.7 AU from Earth and is just 4" wide through a telescope.

Early in the evening on the 29th, you'll find Uranus about 2° south of the bright Moon. Our satellite moves eastward

WHEN TO VIEW THE PLANETS

EVENING SKY

Saturn (southeast)
Jupiter (east)
Uranus (east)
Neptune (east)

MIDNIGHT

Saturn (southwest)
Jupiter (southeast)
Uranus (east)
Neptune (south)

MORNING SKY

Mercury (east)
Venus (east)
Jupiter (west)
Uranus (west)

and later that night passes through a group of 5th- and 6th-magnitude stars, occulting two of them (63 and 65 Arietis) from some parts of the country.

Venus is a brilliant morning star, starting the month 7° west of Regulus, Leo's brightest star. At magnitude -4.7, Venus is visible in the eastern sky soon

COMET SEARCH | The clown with green hair

PEAKING AT 8TH MAGNITUDE,

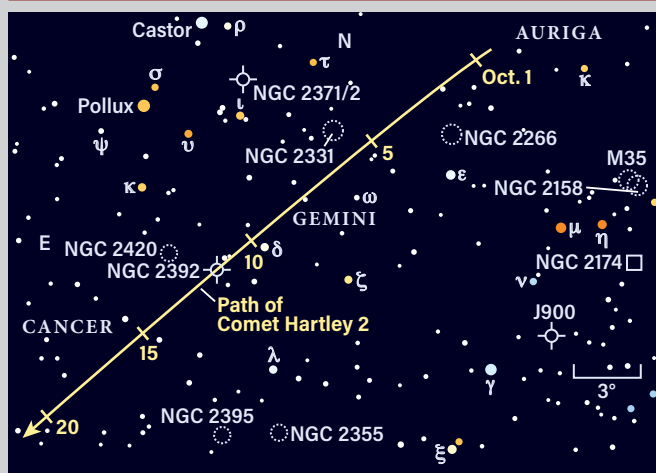
Comet 103P/Hartley (also called Hartley 2) will be a decent telescopic sight after midnight from country skies with a 4-inch scope. Binoculars may pull it in, too. From the suburbs, it's in range of a 10-inch scope.

Although Hartley 2 passed closest to Earth last month, it is still closing in on the Sun for perihelion on the 12th. The mile-long, bowling-pin-shaped dirty snowball orbits Sol every 6.48 years. We get a good chance at it every 12.96 years, but that slight shortfall in time means that for each return, Earth arrives later so the comet is farther and fainter. Next month is our last view brighter than 10th magnitude for a few decades.

We do get a consolation prize:

On the 12th and 13th, the "hairy star" is only 0.5° from NGC 2392 in Gemini, sometimes called the Lion or the Clown-faced nebula. To imagers, both will be green. The higher surface brightness of the planetary nebula will trigger our green cone receptors through 10-inch scopes, but visually the comet's fuzz will remain ashen gray. We are seeing the comet almost head-on. Can you notice which side is out of round?

Comet 103P/Hartley 🔭

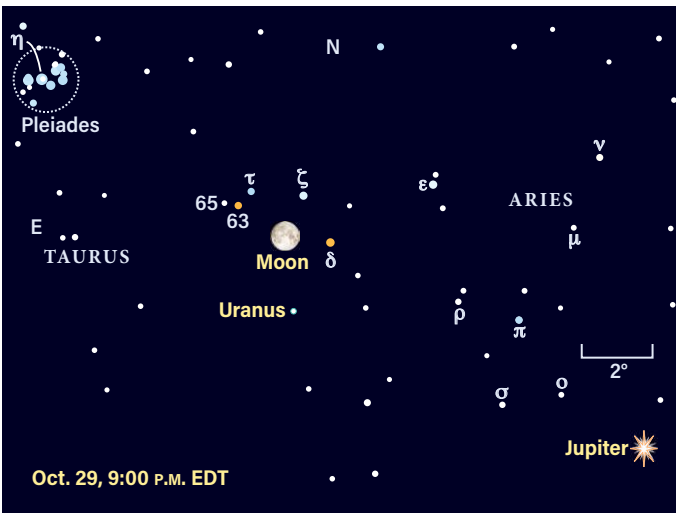


Comet Hartley 2 covers a fair bit of sky this month, skating closely past NGC 2392 just before the 15th. Go online to find information on the comet's location later in October.

LOCATING ASTEROIDS |

A drop in the water

Lunar action



On Oct. 29, use the Moon to find Uranus with binoculars or a telescope. Later in the evening, our satellite moves northeast, occulting 63 and 65 Ari for some observers.

after rising around 3:30 A.M. local daylight time. By the 10th, Venus is magnitude -4.6 and stands 2.5° south of Regulus. The pair is joined by a waning crescent Moon about 5° away.

Venus traverses southern Leo and on the 31st stands 6° northwest of Beta (β) Virginis. Through a telescope, Venus' disk is a $32''$ -wide, 37-percent-lit crescent on the 1st. The disk shrinks to $22''$ by the 31st and is 54 percent lit. Venus reaches western elongation (46°) on the 23rd. The planet is now 50 percent lit, called dichotomy. However, observers may see the actual moment of dichotomy occurring before or after this date. This is called Schröter's effect, named for the German astronomer who first noted it, in 1793. At western elongations, dichotomy can be up to 6 days late. The phase is best determined in bright twilight.

Venus also acts as a nice guide for the line of the ecliptic if you want to observe the zodiacal light. For a few days around

New Moon, check for this faint cone-shaped glow rising from the eastern horizon before morning twilight begins.

Mercury makes a brief morning appearance at magnitude -1.1 early in the month. Its elongation from the Sun is decreasing quickly. On the 1st, the planet stands 4° high in the east 50 minutes before sunrise. By the 4th, it has dropped to 2° high at the same time. Mercury reaches conjunction with the Sun Oct. 20 and returns to the evening sky later next month.

Mars is too close to the Sun for observation this month.

An annular eclipse of the Sun takes place Saturday, Oct. 14. Just six months before the much-anticipated 2024 total solar eclipse, it offers a great opportunity to practice observing that event. Most of the U.S. will see a partial eclipse with diminishing percentage farther from the central track. Only observers along that center line will see the annular eclipse.

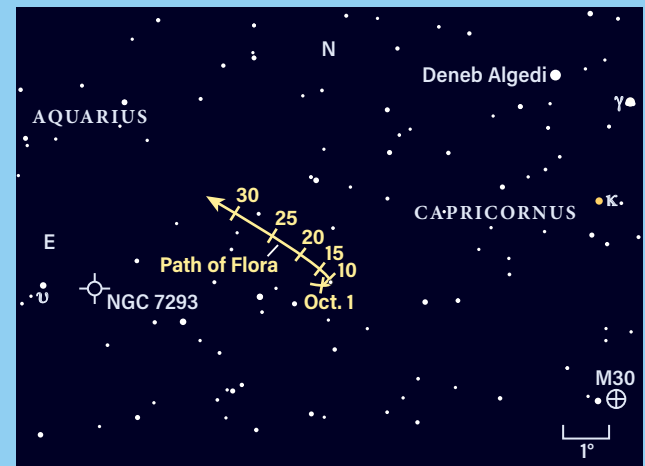
The track of annularity,

CAN YOU MOVE YOUR SCOPE straight up and down? That's all it takes to locate the large asteroid 8 Flora this month. Just before 10 P.M. local daylight time, Saturn and Iota (ι) Aquarii cross the meridian, the imaginary line rising overhead from the southern horizon. Shift the view 7° directly down to land on Flora. If you don't know your exact field of view, there are online calculators for any scope-eyepiece combination.

Use the chart to keep tabs on the patterns of triangles, voids, and clumps as you near the spot. On the 7th and 8th, Flora forms a tight pair with a magnitude 7.4 field star. The 85-mile-wide, nearly spherical mountain will be notably fainter at magnitude 9.2. You likely won't see any movement during your observing session because Flora is just exiting a hairpin retrograde arc, its motion briefly parallel to Earth's. Take a break from Oct. 22 to 25, when the passing waxing gibbous Moon throws out its veil of light.

Flora was discovered by Englishman John Hind in 1847, decades after Giuseppe Piazzi had pegged 1 Ceres in 1801.

Changing directions



Flora executes a tight turn just a few degrees south of Saturn's location this month. The ringed planet lies north of this chart's field of view.

where the Moon crosses exactly in front of the Sun but leaves a brilliant ring at central eclipse — and subsequently always requires eclipse glasses to observe — runs from Oregon to Texas. Annularity begins near Eugene, Oregon, just before 9:17 A.M. PDT and ends in Texas near Corpus Christi around 12:01 P.M. CDT.

The eclipse continues through Mexico, Belize, Honduras, Nicaragua, and Panama. It then enters Colombia and begins to turn eastward across Brazil. The path enters the Atlantic Ocean south of Natal, where the Sun

sets during the final partial phase.

Two weeks after the annular eclipse, a partial eclipse of the Moon occurs Oct. 28, visible in Europe, Africa, India, and Asia. Observers in the northeastern U.S. might see the Full Moon rise with a dusky southern edge, the result of the final stages of the penumbral eclipse. ☾

Martin Ratcliffe is a planetarium professional with Evans & Sutherland and enjoys observing from Salt Lake City. **Alister Ling**, who lives in Edmonton, Alberta, is a longtime watcher of the skies.



GET DAILY UPDATES ON YOUR NIGHT SKY AT
www.Astronomy.com/skythisweek.

A timeline of famo

Nov. 30, 3340 B.C.

Spiral petroglyphs on the Loughcrew Cairn L Megalithic Monument in Ireland indicate this was the earliest observed solar eclipse for which a record exists.

March 30, 1578 B.C.

The partial solar eclipse that was closer to total than any other occurred. At maximum, the Moon's diameter was 0.99985 that of the Sun.

May 3, 1375 B.C.

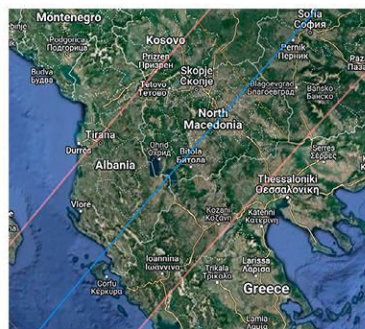
A total solar eclipse on this date is described in carvings on a clay tablet found in 1948 in the ancient port city of Ugarit, Syria. Totality was north of the city; the city itself saw "only" a 98-percent partial eclipse.

April 16, 1178 B.C.

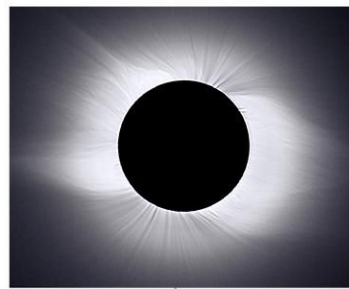
This is possibly the eclipse mentioned in Homer's *Odyssey*. In parts of Ancient Greece, totality would have lasted some 4½ minutes.



ROB HURSON/WIKIMEDIA COMMONS



XAVIER JUBIER



ANTHONY ANTONAMITIS



BEHAR BAKSHANDEH

Feb. 22, 720 B.C.

This was the first of 36 solar eclipses that were observed in China and included in Confucius' book, *Chunqiu* (*The Spring and Autumn Annals*).

May 28, 585 B.C.

According to Herodotus, Greek philosopher Thales of Miletus predicted this eclipse. It stopped a battle between the Medes and Lydians, after which both sides negotiated a peace treaty.

Nov. 24, A.D. 29

The Eclipse of Phlegon occurred, so called because that Greek historian wrote an account of it. Some scholars associate it with the darkness mentioned in the Bible at Christ's crucifixion, but the eclipse was only 80 percent partial in Jerusalem.

March 20, 71

The Greek philosopher Plutarch was the first to describe the corona, writing about this eclipse in his book *De Facie in Orbe Lunae* (*On the face which appears in the Orb of the Moon*).

Dec. 7, 150

The longest annular eclipse between 2000 B.C. and A.D. 3000 occurred. At the point of maximum annularity, the Moon's disk was surrounded by the Sun for 12 minutes 23 seconds.

July 17, 334

The Roman senator Julius Firmicus Maternus gave the earliest description of a prominence (an eruption of gas above the Sun's surface) during this eclipse. Interestingly, this event was an annular eclipse.

July 19, 418

During the total phase of this eclipse, Byzantine Church historian Philostorgius drew a sketch that showed a comet — the first one ever discovered during an eclipse.

Nov. 24, 569

This total eclipse, mentioned in the Quran, is the one most scholars believe preceded the birth of the prophet Muhammad. The path of totality was south of Mecca, where he was born.

Nov. 30,
3340 B.C.

May 3,
1375 B.C.

April 16,
1178 B.C.

May 28,
585 B.C.

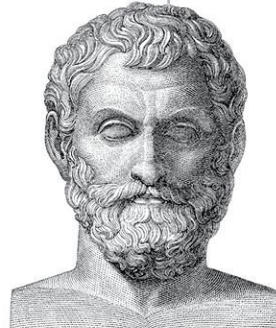
March 20,
A.D. 71

July 17,
334

July 19,
418



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BEHAR BAKSHANDEH

us eclipses

Stroll through history's most significant solar eclipses.

BY MICHAEL E. BAKICH

Feb. 3, 919

The solar eclipse with the shortest totality between 2000 B.C. and A.D. 3000 occurred. When corrections are made for the shape of the Moon, the longest duration of totality was only 2.5 seconds.

Aug. 2, 1133

Numerous accounts connect this eclipse to the death of King Henry I of England. However, Henry didn't die until December 1135. The eclipse could be related to his moving the royal house to Normandy, France.

June 16, 1806

After viewing this total solar eclipse from Kinderhook, New York, astronomer José Joaquín de Ferrer gave the Sun's outer atmosphere its name: the corona, Latin for "crown."

May 15, 1836

English astronomer Francis Baily explained why "beads" of sunlight appear just before and just after totality, and also sometimes during annularity, after recording the phenomenon during this annular eclipse.

July 28, 1851

Russian photographer Johann Julius Friedrich Berkowski took the first successful picture of totality during this eclipse, using a 2.4-inch telescope at the Royal Observatory in Königsberg, Prussia.

Aug. 18, 1868

A new line in the Sun's spectrum was seen by two astronomers: Pierre Jules César Janssen in France and J. Norman Lockyer in England. This line, Lockyer thought, revealed a new element, which he named helium.

May 17, 1882

After English astronomer Arthur Schuster developed the photographic plates he took of this event, he discovered a comet — the first one found photographically during totality.

Aug. 19, 1887

During the eclipse, Russian chemist Dmitri Mendeleev rose to an altitude of some 2 miles (3.2 kilometers) in a hot-air balloon. His had a spectacular view of

the solar corona, but because his assistant remained on Earth, Mendeleev had to limit his studies to manage the balloon.

May 29, 1919

In 1916, Albert Einstein published his general theory of relativity, which states that space-time is curved by the presence of mass. During this eclipse, two teams of astronomers took pictures of stars near the Sun that proved gravity warps space.

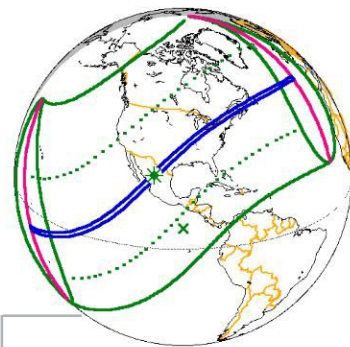
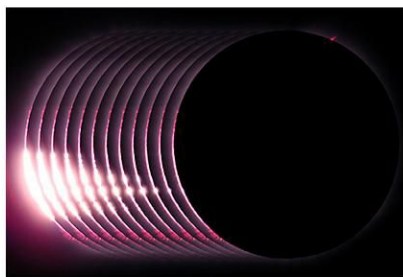
April 8, 2024

This date will be your next chance to see totality — up to 4 minutes 27 seconds — in the U.S. Start making travel plans.

Aug. 12, 2045

After 2024, the next Great American Eclipse will sweep across the U.S. from California to Florida. Maximum totality will be 6 minutes 6 seconds. ☿

Michael E. Bakich is a contributing editor of *Astronomy* and author of *Your Guide to the 2024 Total Solar Eclipse* (available at MyScienceShop.com).



June 16,
1806

May 15,
1836

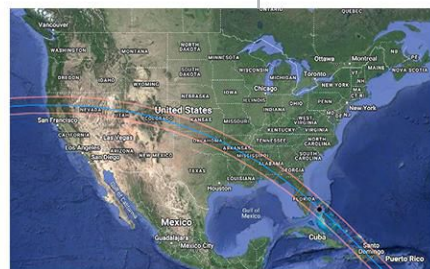
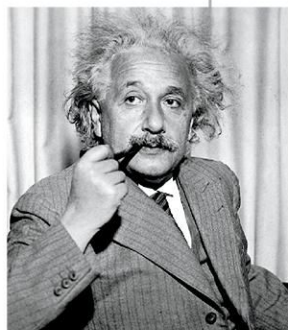
July 28,
1851

Aug. 19,
1887

May 29,
1919

April 8,
2024

Aug. 12,
2045





Explore great summer nebulae

The heart of the Milky Way provides lots of observing opportunities. **BY KEVIN RITSCHER**

Many good things come in threes: the Three Musketeers, the Three Tenors, movie and book trilogies, and more. There seems to be something symmetrical, beautiful, and satisfying when using the power of three.

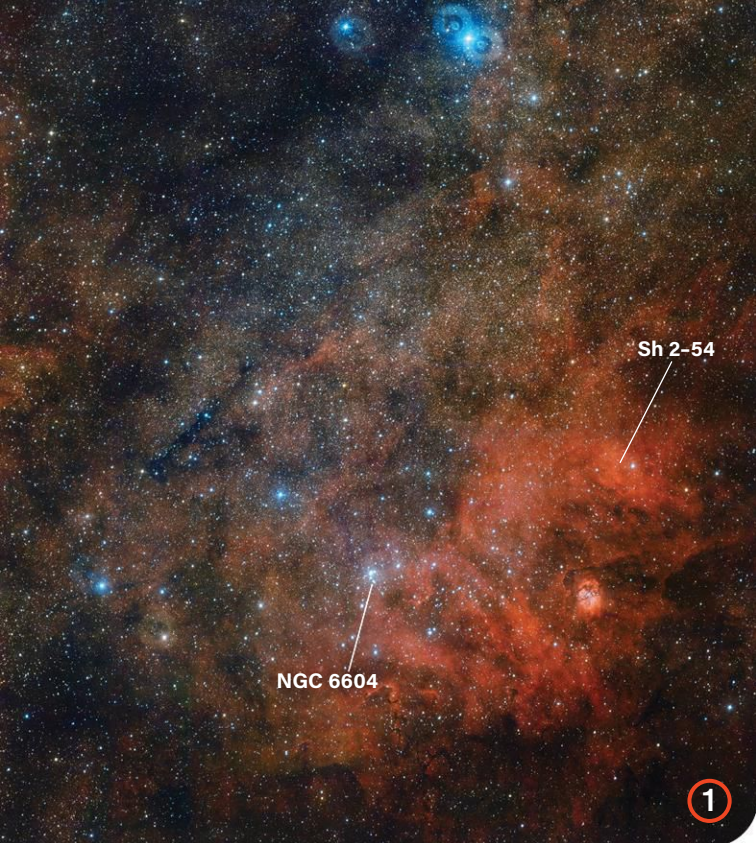
With that mindset, I was immediately impressed by my first glimpse of the European

Southern Observatory's 2017 release of a mosaic image, titled "VST Captures Three-In-One." These objects — the Swan Nebula (M17) in Sagittarius, and the Eagle Nebula (M16) and Sharpless 2-54, both in Serpens — are part of the summer Milky Way. The mosaic consists of images taken by the VLT Survey Telescope (VST), atop Cerro Paranal in Chile.

Commissioned in 2011, the VST has a 2.6-meter mirror feeding a 268-megapixel camera that delivers wide-angle images covering a 1° by 1° area of the sky. But even that wasn't big enough to make the mosaic, which covers an area about 6° by 3° . Examine the image above and you'll see the three nebulae splashed across the panorama. As soon as I saw the image, I wondered

how much of it I could actually see.

Most importantly, you must observe beneath a dark sky to appreciate what this image has to offer. I observed from a hilltop near SkiesAway Remote Observatory about 35 miles (56 kilometers) northwest of Paso Robles, California, under Bortle class 2 skies. I employed binoculars and small (3.2-inch), medium

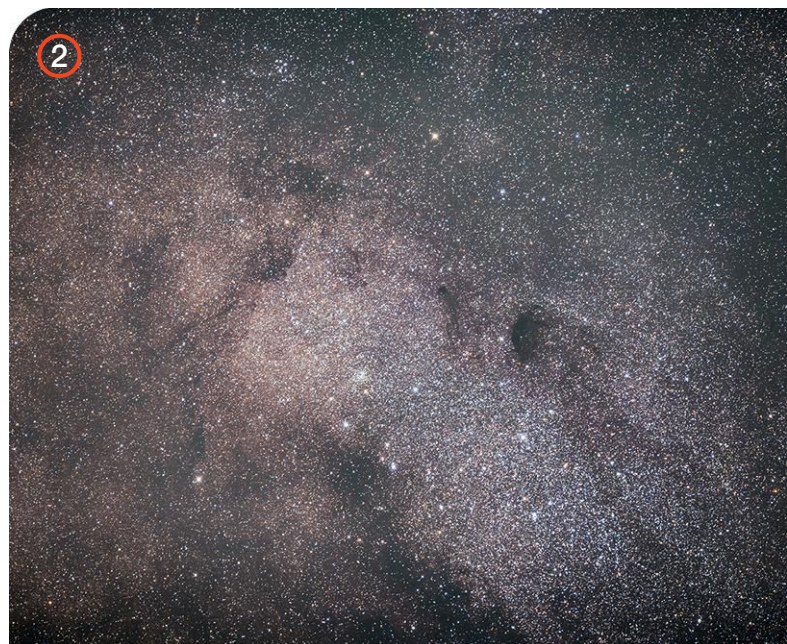


(6-inch), and large (14- and 17.5-inch) telescopes, and was delighted in what I could tease out of the sky.

Binoculars first

Let's examine the three nebulae in the image starting from the south and working north. Just outside the southern boundary of the image (left

side), are three bright objects almost in an east-west line that form a visual "barrier" to the three nebulae: M25, M24 (also known as the Small Sagittarius Star Cloud), and M23. I aimed my 8×42 wide-angle (7° field of view) binoculars at M24 and scanned north. With the top of M24 at the bottom of the field of



1. ESO's VLT Survey Telescope captured this 3-gigapixel image of the deep sky in the constellations Serpens and Sagittarius. North is to the right. ESO

2. The Small Sagittarius Star Cloud (M24) is one of the many objects in this region within the grasp of binoculars. DEAN SALMAN

3. The Swan Nebula (M17) is a bright star-forming region some 5,500 light-years away in the constellation Sagittarius. GERALD RHEMANN



view, the entire region was visible, and I felt as if Homer Pyle was shouting, "Surprise, surprise, surprise!" in my ear.

Through these modest binoculars I could see the nebulosity associated with M17 plus the emission cloud IC 4701 to its west. M16 was also visible, seeming brighter than M17, at least at its core. I also saw open cluster NGC 6604, which is surrounded by emission nebula Sh 2-54. At the bottom edge of the field was the small open cluster M18.

The view was unexpectedly good, so I switched to tripod-mounted 10×70 binoculars. Starting back at M24, I could clearly see three dark nebulae along the northwestern side of the star cloud, and a fourth seemed to be fading in and out. The four dark nebulae are Barnard 307, 93, 92, and 304.

Through the 10×70s, the telltale shapes of M17 and M16 were even more pronounced. Sh 2-54 was faint but directly visible, though I couldn't resolve stars in NGC 6604. It was just a small, bright knot. To the east of



Sh 2-54, the dark nebula B95 was clearly visible.

Two other emission nebulae lie nearby. Both are rather small and quite difficult to see. About 3° west of M16 is Sh 2-46 (not in the image). And Sh 2-53 lies about 1.5° northeast of M16. The loose open cluster NGC 6625 was also visible. It's 0.5° wide and about 1.5° east of NGC 6604.

Telescopic enhancement

I then switched to my short-focal-length 3.2-inch refractor. With a 22mm eyepiece, it gives a magnification of 23x. Mostly, it confirmed my binocular sightings and offered higher-resolution views of the vista broken into about three sections — nothing new, but all brighter.

Next, I used my 6-inch f/8 refractor to zero in on some of the smaller targets. Trumpler 32 was easy to see with a 22mm eyepiece (55x) about 1° north-northwest of M16. This cluster looked like a small, round patch of background glow. Higher powers revealed a few individual stars, but the faint glow remained.

Boosting the power to 70x (17mm eyepiece) gave spectacular views of both M17 and M16. M17 is so named because it looks like its namesake swan, while M16 looks like an eagle with outstretched wings.

I noted both these visual impressions clearly, and each was enhanced with an Oxygen-III filter. Interestingly, a Hydrogen-beta filter worked almost as well, especially on M16.

Eyes of the Eagle

Through both the 3.2-inch and the 6-inch, I noticed that the two brightest stars in NGC 6611, the cluster associated with M16, have a truly



4. The tiny open cluster at the center of this image is NGC 6604. The nebula surrounding it is Sharpless 2-54. CHUCK KIMBALL

5. Some sharp-eyed observers may be able to glimpse open cluster M23 without optical aid, but binoculars will definitely reveal it. THOMAS V. DAVIS



haunting appearance. They are identical in brightness and spaced close together. To me, they looked like a pair of ghostly eyes peering back from the Eagle's tilted head.

While I examined M16, I wondered if the Pillars of Creation were visible. In a word: almost. I experimented with higher magnifications (up to 240x) with and without nebula filters. At about 86x (14mm eyepiece), I could start to see brighter and darker linear markings in the brightest part of the nebula. There was something there, but I couldn't make out a definite shape that I would call a pillar.

So, I dragged out my 14-inch SCT; still no luck recognizing a pillar. Next, I brought out the 17.5-inch reflector. Again, I could tell something was there but I couldn't point to a feature that you'd recognize as a pillar.



Textured nebulae

Taking the time to bring out the big guns was well worth it. The views enhanced the amazement I felt at the binocular observations of the VST's three nebulae. Through the larger scopes, the brighter portions of M17 and M16 increased in texture — I could see ripples in the gas clouds and dark dust lanes intruding into the glowing gas. I didn't notice a larger extent of the nebulae, but rather enhanced

definition within the previously visible area. Through the 17.5-inch with an OIII filter, the dark nebula shaping the northern portion of M16 seemed three-dimensional. Unfortunately, there's no way to see the faint nebulosity of Sh 2-54 in these scopes, although careful observation revealed a few internal ripples that are part of the nebula.

I'm adding these targets to my bucket list to track down from the Southern



6. Although M25 is a loose open cluster, you'll spot its magnitude 4.6 glow without optics from a dark site.

RICHARD HAMMAR

7. This amateur image of the region captures a bit more sky to the south than the VST image. In this one, M16 is to the far right. TERRY HANCOCK



The Dark Toad

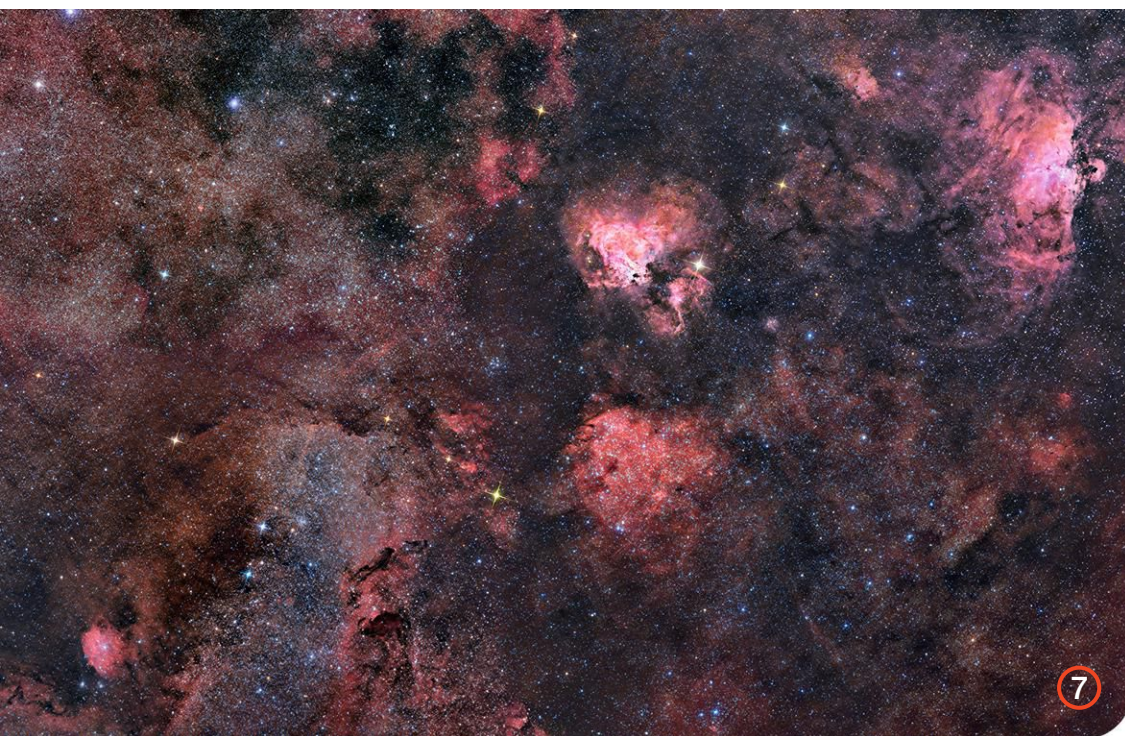
If you look at the right (north) side of the VST image, you'll see a bright knot of nebulosity in Sh 2-54, almost directly north of NGC 6604. Visually, this is a faint circular area, more of an outline than a patch through the 6-inch with an OIII filter.

Next, go back to NGC 6604 on the image. Look west — about halfway from the cluster to the bottom of the frame, you should see a dark outline surrounded by a rim of brighter emission. If you enlarge the image online (<https://www.eso.org/public/news/eso1719/>), you can see a shape that I nicknamed the Dark Toad Nebula because it looks like a frog sitting on a lily pad. Through the 6-inch, it's like the pillars: I can tell something's there but can't quite make it out.

Observe!

With just decent binoculars under a dark sky, you can enjoy the VST's three nebulae and a lot more. After spending a few nights chasing objects in this vista, I have yet more targets I want to track down in addition to the desire to definitely see the Pillars of Creation. Set your goals according to your optics, but by all means, head out to observe soon. Clear skies! ☾

Kevin Ritschel helped develop the first commercial go-to telescopes to facilitate deep-sky observing.



M17 is so named because it looks like its namesake swan, while M16 looks like an eagle with outstretched wings.

Hemisphere, where they're higher in the sky. From central California, at their highest, around 11 P.M. in early July, these objects are about 45° above the southern horizon — OK, but not ideal. Observing in the Northern Hemisphere, I generally don't try to pick out fine details

unless the object is 15° higher than this.

There are other targets to chase in and near the VST image. Two loose open clusters lie near M17: NGC 6596 sits 1° southwest, next to the emission region IC 4701; and NGC 6561, which is 2.5° west of M17. Both are within reach

of the 6-inch telescope. Another open cluster is NGC 6645, about 3° east and slightly south of M17. This 15'-wide ball of many fine stars looks like a small version of the Wild Duck Cluster (M11) and glows relatively brightly at magnitude 8.5.

Our 13th annual STAR PRODUCTS

BY PHIL
HARRINGTON

Each year, we search the globe to bring you a wide variety of astronomical products. Whether you're new to the hobby and science or a seasoned veteran, there's something here for you. Here are *Astronomy's* Star Products for 2023, presented in no particular order.

Phil Harrington is a contributing editor of *Astronomy* and a dedicated equipment collector.



SVBONY SV215 Zoom Eyepiece for Planetary Observing

SVBONY's 1¼" SV215 zoom eyepiece is designed with high-power viewing in mind. The SV215 maintains the same focus, 56° apparent field of view, and 10mm eye relief across the entire range of focal lengths. Other features include click stops at 3, 4, 5, 6, 7, and 8mm, and a foldable eyecup.

\$149.99 •
www.svbony.com

Explore Scientific ReflexSight Non-Magnifying Finder

Explore Scientific's ReflexSight is a different kind of finder. While it fits onto popular dovetail bases, its "multi-dot" reticle design features 0.5°, 2°, and 4° circles, so field stars won't be blocked from view. The brightness is also adjustable. A ¼-20 threaded adapter in the base also lets you connect the ReflexSight to piggyback camera adapters and tripods.

\$69.99 •
www.explorescientificusa.com





3 Heat Holders Chunky Rib Roll Up Hat

It's important to keep your head warm when outside in cold weather, especially during long winter observing sessions. The Chunky Rib Roll Up Hat from Heat Holders is woven from supple yarn and features a HeatWeaver plush insulating liner designed to keep your head warm as nighttime temperatures drop. The hat is available in a variety of colors.

\$22.99 • www.heatholders.com



6 APM 8x56 Magnesium ED APO Binoculars

Germany's APM Telescopes recently introduced the latest of their lightweight magnesium-bodied ED binoculars, the 8x56 MS ED. The objectives use FK61 ED glass and BAK-4 Porro prisms. All optical surfaces are fully multicoated, and both barrels are sealed and nitrogen-purged. The eyepieces have a real field of 7.5° and eye relief of 23mm.

461.34€ • www.apm-telescopes.net



4 Celestron Tabletop Tripod for NexStar SE Telescopes

Catadioptric telescopes are portable, but they still take some effort to set up. To address that, Celestron introduced a tabletop tripod for its fork-mounted NexStar Evolution and NexStar SE instruments. This compact base is half the size and weight of a standard tripod. Open the legs, set them on a flat surface, attach the scope, and you're ready to go.

\$99.95 • www.celestron.com

5 Altair Astro Starwave 80EDT-R Triplet APO Travel Refractor

Need a companion for the April total solar eclipse? Altair Astro's Starwave 80EDT-R apochromatic refractor features a triplet 3.1-inch f/6 ED objective with all air-to-glass surfaces multicoated. The white aluminum alloy tube has CNC-machined mounting rings, a dovetail bar, a dual-speed focuser, and a retractable dew shield.

£899 • www.altiraastro.com



7 Sky-Watcher Virtuoso GTi 150P

This 6-inch f/5 Newtonian combines Sky-Watcher's innovative collapsible tube assembly with the one-armed Virtuoso GTi tabletop go-to mount. The Virtuoso GTi 150P weighs 19 pounds (8.7 kg) and measures 16 inches (40.6 cm) when collapsed, and comes with 10mm and 25mm eyepieces, a helical focuser, a red dot finder, and a dust cap.

\$470 • www.skywatcherusa.com





8 iOptron HEM27 Hybrid EQ Mount

The iOptron HEM27 appears to be a regular German equatorial mount, except there's no counterweight. That's right — the lightweight HEM27 can balance a load of up to 29.7 pounds (13.5 kg) thanks to its innovative drive, which uses iOptron's Go2Nova hand controller. A dual saddle will accept both Vixen and Losmandy-D telescope bases.

\$1,998 • www.ioptron.com

10 Pentax XW 85° Eyepieces

Pentax's XW line of eyepieces is one of the best. The new 2-inch models, a 16.5mm and a 23mm, expand the selection as well as the field of view. Others in the XW line have 70° apparent fields of view, but these increase that to 85°. Star images are sharp thanks to a new optical system using seven lens elements in five groups. Eye relief is 20mm.

\$479.95 and \$499.95 • www.us.ricoh-imaging.com



9 German Precision Optics Passion HD 10x50 Binocular

The Passion HD 10x50 features fully multicoated ED doublet objectives paired with roof prisms that have phase-corrected coatings. It has a 5.9° field of view and 19.5mm of eye relief. The sealed, rubber-armored magnesium housing weighs just 33.9 ounces (0.96 kg) and includes a locking center focus knob and twist-up aluminum eyecups.

\$1,359.99 • www.gpo-usa.com



11 Kendrick Solar Filter with Built-in Sun Finder

Rather than aim your scope at the Sun using shadows as your guide, Kendrick Astro Instruments has incorporated a Sun finder into its solar filters. Secure the filter to the front of your scope and point the instrument toward the Sun until sunlight shines through the finder's pinhole onto the tiny projection screen.

\$77.83–\$169.62 • www.kendrickastro.com



12 Askar 80PHQ Quadruplet APO Astrograph

Askar's compact 3.1-inch f/7.5 refractor features a four-element Petzval optical system. Included are a dual-speed rack-and-pinion focuser, mounting rings, a lens hood, a Vixen-style dovetail plate, a carrying handle, and photographic adapters. The tube measures 17.6 inches (44.8 cm) long with the hood stowed, and weighs 8.6 pounds (3.9 kg).

\$1,495 • www.askarlens.com





13 My Science Shop Percival Lowell Mars Globe

The dawn of the 20th century saw the height of Mars mania. The excitement stemmed from Percival Lowell, who recorded a fantastic array of what he thought were canals crossing the Red Planet. This 6-inch (15 cm) globe is a reproduction of the one created by Lowell himself. It comes with an informational flyer and acrylic base with built-in magnifier.

\$34.95 • www.myscienceshop.com



14 Avalon EVO Zero HQ Mount

The EVO Zero from Italy's Avalon Instruments is a compact equatorial mount. It uses a pair of 400-step motors for backlash-free tracking. It features a Vixen-style mounting plate and includes Avalon's StarGo system, which can be controlled by many popular smart-device apps. The carrying capacity is 28.7 pounds (13 kg), yet the mount weighs less than 11 pounds (5 kg).

2,900€ • www.avalon-instruments.com

15 Explore Scientific

iEXOS-100-2 PMC-Eight Mount

The iEXOS-100-2 German equatorial mount uses Explore Scientific's Precision Motion Control-Eight (PMC-8) to navigate the night sky. Rather than a single processor, the iEXOS-100-2 uses eight independent CPUs. This results in better accuracy, efficiency, and reliability. Go-to control using the included app allows the mount to be controlled either by Wi-Fi or Bluetooth.

\$349.96 • www.explorescientificusa.com



16 Astro-Physics 110mm f6 StarFire GTX

The new Astro-Physics StarFire GTX serves three functions. First, its compact size makes it an ideal travel companion. Second, its triplet 4.3-inch optical system will cover a full-format CMOS chip for imaging. Third, it offers excellent visual observing. The scope comes with a focuser, adapters, a retractable dew shield, a dust cover, and a carrying case.

\$6,750 • www.astro-physics.com



17 Sky-Watcher Evolux 82ED Doublet Apo Refractor

This 3.2-inch refractor is great for wide-field imaging or visual observing. It features a newly designed f/6.45 two-element fully multicoated apochromatic objective. It comes with a retractable dew shield, a two-speed focuser, a dovetail mounting plate, dual finder mounts, and a case. The scope weighs just 6.5 pounds (3 kg) and measures 16.4 inches (41.6 cm).

\$629 • www.skywatcherusa.com



18 Rainbow Astro RST-135 Mount

The RST-135 uses a strain wave gear, popular in industrial robotics for its zero backlash. This mount also features built-in GPS and Wi-Fi so that it can be controlled via the SkySafari app on your smartphone or tablet. The RST-135 weighs just 7.3 pounds (3.3 kg), but can support up to 29.7 pounds (13.5 kg). A dovetail mounting plate and a tripod are both sold separately.

\$3,895 • www.rainbowastro.com



19 Celestron StarSense Explorer 10

Like the smaller StarSense instruments, Celestron's largest member, a 10-inch f/4.7 Dobsonian, uses the StarSense app to calculate the telescope's position in real time. Then it directs the user to move the scope to find objects. Included are a 25mm Plössl eyepiece, a 2-inch Crayford focuser, a smartphone dock, a red dot finder, an eyepiece rack, and a collimation tool.

\$1,099.95 • www.celestron.com

20 Meade 6-inch f/4.1 LX85 Astrograph Reflector

This is your ticket to great imaging. It combines a fast Newtonian reflector with a tripod-mounted go-to German equatorial mount. It comes with a 26mm Super Plössl eyepiece, a 2-inch focuser, a 1¼" eyepiece adapter, an 8x50 finder scope, and a 9-pound (4 kg) counterweight. A 12-volt DC power source, sold separately, is required.

\$1,999.99 • www.meade.com



21 Rigel Systems wifi-Aline Collimation Tool

The wifi-Aline makes collimating reflectors easy. Insert the wifi-Aline tool into the focuser and turn it on to wirelessly transmit a real-time video feed of the telescope's optical path to a paired tablet, smartphone, or computer's display. The wifi-Aline superimposes three coaxial target rings and a crosshair to guide the user in collimating the primary and secondary mirrors.

\$179.95 • www.rigelsys.com

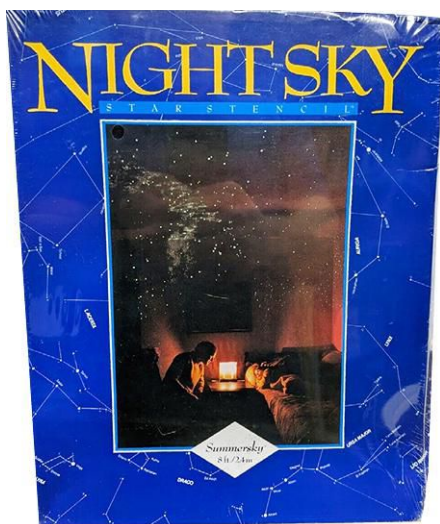




22 Starlight Xpress Oculus PRO All-Sky Camera

This weatherproof camera delivers either a 150° or a 180° fisheye view of the sky, depending on the choice of lens. A built-in dew-prevention system automatically turns on when humidity is high, but will not heat up the CCD chip. The polycarbonate enclosure can be permanently mounted to a post or temporarily to a tripod.

\$1,393 • www.sxccd.com



24 Ursa Major Stencils Night Sky Star Stencil

Turn any room into a planetarium with this kit, featuring either the summer or the winter sky. Each kit includes stencils, adhesive, glow-in-the-dark paint, a brush, and complete instructions. After affixing the stencil using the supplied non-staining adhesive, brush the paint through the constellation holes. Kits are available in 8- and 12-foot (2.4 and 3.7 m) sizes.

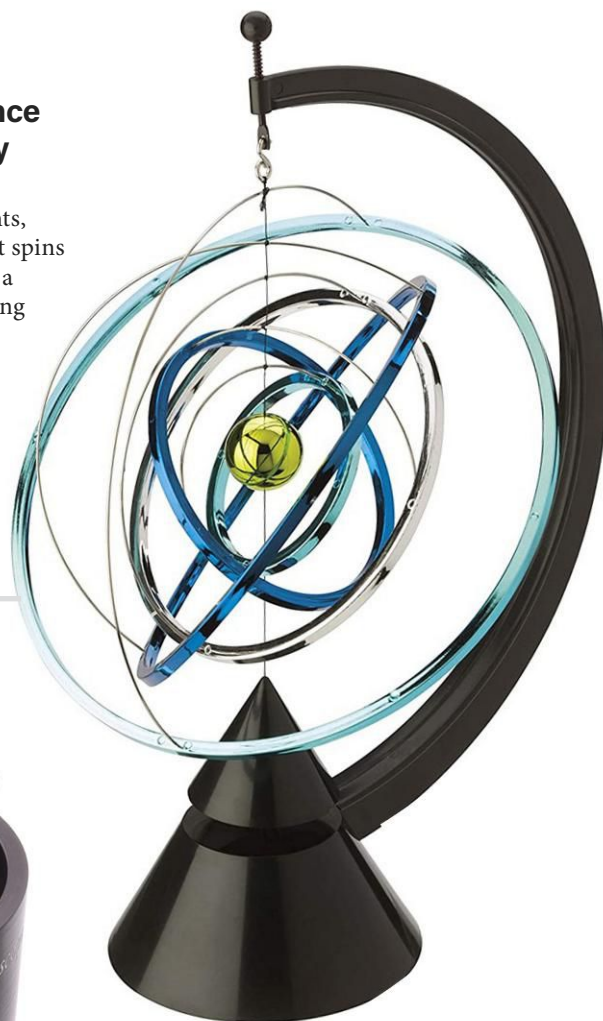
\$54.99 and \$67 •

www.ursamajorstencils.com

23 My Science Shop Galaxy Kinetic Art

Perfect for those cloudy nights, this mesmerizing work of art spins in several directions around a single axis of rotation, creating kinetic art. The effect can be almost hypnotic as you watch the central cone and five metallic "orbits," all twisting around a thin wire axis.

\$26.99 • www.myscienceshop.com



25 Vernonscope 2" 2.4x Dakin Barlow

The venerable 2" Dakin Barlow from Vernonscope will still deliver 2.4x with any eyepiece. But by taking the Barlow apart and screwing the bottom into a 2" eyepiece as you would a filter, the net result is a 1.5x increase.

\$289 • www.vernonscope.com

26 TEC APO200FL F/11 refractor

This observatory-class 8-inch refractor from Telescope Engineering Company is not for the faint of heart. It measures 91.5 inches (233 cm) long and weighs 46 pounds (21 kg). Inside, the apochromatic doublet features a fluorite inner element to optimize color correction. The APL200FL also includes a Starlight Instruments Feather Touch focuser and tube rings.

\$29,600 • www.telescopengineering.com



27 Zeiss 10x40 SFL Binoculars

These binoculars are designed for compactness. Optically, the objectives and roof prisms offer 90 percent light transmission. It takes only 1.4 turns of the focus wheel to go from 4.9 feet (1.5 m) close focus to infinity. The housing is rubber-armored, waterproof, and nitrogen-purged. The SFLs weigh only 22.6 ounces (640 g) and offer 18mm of eye relief. **\$1,649.99 • www.zeiss.com**



30 ZWO ASIAIR Mini Wireless Imaging Controller

The ASIAIR Mini from ZWO is a do-it-all device that lets you remotely control DSLRs or ASI cameras via Wi-Fi on your phone or tablet. It runs on 12 volts and features four 12VDC outputs, a shutter-release port for DSLRs, four USB 2.0 ports, and a USB Type-C port. All this fits in a case that measures 3 inches by 2 inches by 1 inch (7.8 cm by 5.2 cm by 2.6 cm). **\$199 • www.astronomy-imaging-camera.com**



28 Stargazer Unlimited Eyepiece Totes

These cases are made from injection-molded polypropylene copolymer resin, known for its impact strength and stress-crack resistance. The totes come in several configurations depending on the size and number of eyepieces you want to store. Red LED backlighting that turns on automatically when you open the cover is also available as an option. **\$149–\$159 • www.stargazerunlimited.com**



29 Levenhuk Atom Digital DNB200 Night Vision Binoculars

These binoculars combine night-vision technology, a digital converter, an infrared illuminator with seven brightness levels, and an LCD screen. Users can visually observe targets both day and night as well as take high-quality photos and HD video using the built-in recorder. Optical magnification is 4x, but a digital zoom expands the range to 20x. **\$169.95 • www.levenhuk.com**



31 Omegon Pro Kolossus Binocular Mount

Giant binoculars show incredible views if you can support them steadily. This parallelogram mount from Omegon can support binoculars up to 25x100 with ease. The three-part swivel arm lets you aim at any sky location. Once you find a target, it's easy to share the view with others simply by pulling the two handles up or down. **\$679 • www.omegon.eu**



32 TPO UltraWide 180 f/4.5 Astro- photography Lens & Guide Scope

This 40mm f/4.5 scope is built around a triplet apochromatic objective. It attaches to cameras with an M42 T-ring, sold separately. Included are two extension tubes, tube rings, a Vixen-style dovetail plate, a quick-release camera plate, and a 1¼" eyepiece adapter. The UltraWide 180 weighs 13.9 ounces (395 g) and measures 5.7 inches (14.5 cm).

\$381.65



34 4M KidzLabs Create A Night Sky Projection Kit

Who among us doesn't like to travel to a planetarium, especially with children in tow? This kit brings the planetarium to you. It includes four cardboard panels that fold around a battery-powered light. After assembly, turn it on to project the northern and southern skies on walls and ceilings.

\$15.99 • www.4m-ind.com

33 Sumerian 16-inch Canopus Dobsonian

This large Dobsonian-mounted reflector features Guan Shang optics from Taiwan, known for their excellent quality. The Canopus includes a handcrafted birch mount, aluminum truss tubes, a Baader Steel Track 2-inch focuser, and other accessories. An equatorial tracking platform is available separately.

3,795€ • www.sumerianoptics.com



35 iOptron SkyHunter Portable EQ/AZ GOTO Mount

This SkyHunter mount weighs just 2.9 pounds (1.3 kg) but can carry an 11-pound (5 kg) scope all night long. That's because the SkyHunter will run for 10 hours on the built-in rechargeable battery. There's also a Wi-Fi adapter for full control. Four tracking rates work in both hemispheres: sidereal, sky and landscape combined, solar, and lunar.

\$648 •

www.ioptron.com



Supercharge your observing

Astronomical League programs let you explore the cosmos, whether you have a 20-inch Dobsonian or just your eyes.



Anyone can get started with observing, thanks to the Astronomical League's programs. Here, the author peers through her telescope in the twilight. MOLLY WAKELING



Getting started in observing can be challenging. Where do you begin? What do you look for? Even seasoned veterans may find themselves asking, "What do I do now?" from time to time.

If you are looking for some focus and direction in your observing, look no further than the Astronomical League. Its programs cover a broad range of targets, telescope apertures, and skill levels — there is something for everyone. When you have completed a program, you can submit your observations and earn a pin and certificate, not unlike a Scouting badge.

For the novice observer, a great place to start is the Constellation Hunter Observing Program. No telescope or prior knowledge is required — just a planisphere, a logbook, and a desire to learn. This program takes you through either 39 (Northern Hemisphere) or 57 (Southern Hemisphere) constellations and asks you to record the date, location, and sky conditions before sketching the visible stars of the constellation. This is a great introduction to navigating the night sky.

For children 10 years and older, the Sky Puppy program is a series of hands-on projects laid out in a workbook. Activities include sketching constellations, identifying stars and bright naked-eye objects, using binoculars to spot targets such as the Pleiades and Albireo, learning constellation myths, and more. Other great options for beginners include Beyond Polaris (a "sky observing 101" program), as well as the Universe Sampler and the Youth Astronomer observing programs.

Submit your observations and earn a pin and certificate.

Once you feel ready to dive into astronomy with a telescope, the Messier Observing Program is a great place to start. You don't need a fancy optic — a 3-inch reflector will do on good nights, and several Messier objects can even be spotted with binoculars. This is a great place to learn how to star-hop and find these objects yourself using star charts.

Solar system programs are another good jumping-off point, especially if you live under light-polluted skies. The Lunar Observing Program is a combination of naked-eye, binocular, and telescopic observations that cover perceived surface shapes, such as the rabbit in the Moon, as well as lunar maria, craters, and other features at various Moon phases.

For the experienced observer looking for a new challenge, several programs are available to explore objects you might not have attempted before. You can chase down Arp's list of peculiar galaxies, bask in the deep red light of carbon stars, peer into the depths of dark nebulae, hunt for Earth-orbiting satellites, learn about stellar evolution and variable stars, and more. For a real challenge, tackle the Herschel 400 list, hunt for active galactic nuclei with a large telescope, dive deeper into the features of the Moon, or learn a new skill such as observing novae or doing radio astronomy.

With the rapid growth of astrophotography, the Astronomical League has begun offering dedicated imaging programs, as well as allowing imaging in some of its traditional observing programs. Programs specifically for imaging include the Imaging — Caldwell Observing Program, Imaging — Messier Observing Program, Spectroscopy Observing Program, and Target NEO Observing Program. The Master Imager Award requires using imaging to complete several programs, including lunar, solar, deep sky, and scientific studies.

Most of these programs require you to be a member of the Astronomical League. If you are not in a club or your club is not a member, you can become a member-at-large for \$40 (U.S. resident), \$50 (international), or \$20 (U.S. youth).

There are many more programs than what I have listed here — 82, to be precise! From complete beginner to experienced veteran, whether you are interested in chasing down elusive dim fuzzies; diving deep into the Sun, Moon, and planets; doing citizen science, outreach, or dark sky advocacy; or imaging it all, there is a program for you.

To learn more about the Astronomical League's observing programs, visit www.astroleague.org/observing-program-division.



BROWSE THE "OBSERVING BASICS" ARCHIVE AT www.Astronomy.com/author/molly-wakeling



BY MOLLY WAKELING

Molly is an avid astrophotographer active in STEM outreach. She is pursuing her Ph.D. in nuclear engineering.

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Queenly clusters

Stellar groups dominate the night sky this fall.



Crisscross Cassiopeia the Queen to find the constellation's characteristic clusters. *ASTRONOMY*: ROEN KELLY



Cassiopeia the Queen reigns over one of the richest regions of the Milky Way north of the celestial equator. This month, we visit some of her lesser-known subjects.

Let's begin with open cluster **NGC 129**. This one is easy to find, as it sits almost exactly halfway between Caph (Beta [β] Cassiopeiae), which marks the western end of the constellation's familiar W pattern, and Gamma (γ) Cassiopeiae at the W's center. Aim there and you'll find the 6th-magnitude star SAO 21457 and, just to its north, a small blur — that's the open cluster. NGC 129 shines at 7th magnitude and holds some three dozen stars in its grip. Many shine below binocular visibility, however. You'll know you're in the right place when you find three 9th-magnitude stars in a tight equilateral triangle, surrounded by a dim glow. The brightest member of the triangle is the golden-colored Cepheid variable star DL Cassiopeiae.

Next, zigzag your way across the W to Epsilon (ε) Cassiopeiae at the eastern end. About 10½° to Epsilon's southeast is 4th-magnitude Eta (η) Persei. Halfway between the two is our next target, the bite-sized cluster **Stock 7** (also known as Markarian 6). This tiny congregation holds some 29 stars, although the exact number is hard to pin down given the rich surroundings. Viewing through my 10x50 binoculars, I can spot four 8th- to 9th-magnitude stars set in a short, fuzzy arc curving north-southwest. My larger 16x70s add several fainter stars that together form a cruciform shape, with two 11th-magnitude stars creating the crossbeam. Other

observers have commented that the shape reminds them of a croissant or an arrow pointing south. Even larger binoculars show that the southernmost star belongs to a tight collection of four points, creating a pretty scene against the starry backdrop.

A 1980 paper in the *Publications of the Astronomical Society of the Pacific*, entitled "A Small Cluster Near IC 1805," examined whether Markarian 6 was a true open cluster and if it was associated with the nearby large Hydrogen-II region IC 1805, nicknamed the Heart Nebula. The cluster overlaps the southern edge of the nebula. The results showed that it is in fact a genuine cluster and lies 1,600 light-years from us. The nebula, however, is believed to be 7,200 light-years away.

The Heart Nebula is tough to make out through binoculars, but might be possible by using a pair of UHC filters.

Markarian 6 may not lie within IC 1805, but another cluster does. Marking the heart of the Heart Nebula, **Melotte 15** (also cataloged as Collinder 26) is a sparsely packed grouping spanning 21' and containing about 40 blue-white and white stellar infernos. The three brightest stars shine at 7th and 8th magnitudes and form an obtuse arrowhead aimed northwest. A fourth 9th-magnitude star at the eastern edge of the cluster serves as the arrow's shaft.

Since we are so close, let's pay a visit to open cluster **Stock 2**. You may know it as the Musclemans Cluster. This name was bestowed upon it by my friend, the late John Davis of Amherst, Massachusetts, three decades ago, and it really caught on. The cluster's stick figure is oriented with the head to the west and the feet to the east. Both arms curl upward, as if he is flexing his muscles.

Cassiopeia the Queen reigns over one of the richest regions of the Milky Way north of the celestial equator.

But recently, I read of another nickname that I thought was also very good because it includes the surroundings: the Dog Walker. First, look beyond Stock 2, across the border into Perseus. There lies the beautiful **Double Cluster**, NGC 869 and NGC 884. They are always one of my first stops whenever I head out this time of year. They also make finding Stock 2 easy, thanks to an arc of stars that curves northwestward toward the Musclemans.

Incorporating this arc of stars and the Double Cluster is what forms the Dog Walker. Stock 2's stick figure is walking the dogs — the Double Cluster — with the arc forming the leash. As a lifelong dog owner, I especially appreciate this broad asterism.

Questions, comments, suggestions? Contact me through my website, philharrington.net. Until next month, remember that two eyes are better than one. ♀



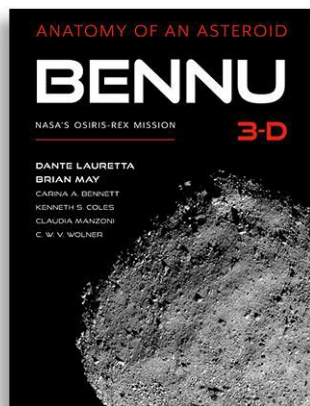
BROWSE THE "BINOCULAR UNIVERSE" ARCHIVE AT www.Astronomy.com/Harrington



BY PHIL HARRINGTON

Phil received the Walter Scott Houston Award at Stellafane 2018 for his lifelong work promoting and teaching astronomy.

NEW PRODUCTS



An asteroid revealed The University of Arizona Press Tucson, AZ

Bennu 3-D: Anatomy of an Asteroid by Dante Lauretta and Brian May is the world's first complete (and stereoscopic) atlas of an asteroid. Its 208 pages are filled

with images collected by the cameras of NASA's OSIRIS-REx spacecraft, as well as other details of the mission to the near-Earth asteroid 101955 Bennu.

\$50.00
520.621.1441
<https://uapress.arizona.edu>

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ABOVE: The Cassini probe breaks up in Saturn's atmosphere in this artist's depiction. The probe was intentionally destroyed to prevent contamination of the planet's moons.

NASA/JPL-CALTECH

RIGHT: A frame from the Illustris Simulation shows a massive galaxy cluster at center. Red, orange, and white colors show hot gas, while the blue and purple filaments depict a cosmic framework of dark matter.

ILLUSTRIS COLLABORATION

Crashing Cassini

Q | CASSINI INTENTIONALLY CRASHED INTO SATURN TO PREVENT CONTAMINATION FROM EARTHLY ORGANISMS. BUT WOULDN'T HUYGENS POSE A MUCH GREATER RISK, AS IT ACTUALLY LANDED ON TITAN?

*Rich Andreano
Lakewood, Colorado*

A | The rationale dominating the decisions to land Huygens on Titan and destroy Cassini in Saturn's atmosphere is that astrobiologists and planetary protection experts are far more concerned about contaminating Enceladus than about contaminating Titan.

This might seem counterintuitive: Titan is of major astrobiological import because its surface and atmosphere are teeming with organic chemicals — including many that are part of the basis of life on Earth and which we think played a role in the origin of life. Titan is also unique as a moon with a substantial atmosphere.

However, due to Titan's cold temperatures (minus 290 degrees Fahrenheit, or minus 179 degrees Celsius), we expect its organic chemicals have not evolved into biology, or at least not Earth-like biology. On Earth, biological reactions depend on water being in a liquid state to act as a solvent via hydrogen bonding, allowing organic molecules to form membranes and thus cells.

While ammonia could be the solvent and the basis for membranes on a super-cold world like Titan, ESA considered the risk of contaminating such a cold biosphere

to be extremely low. The agency states on its website: "The harsh environment is expected to kill microorganisms that may have hitchhiked from Earth on board the clean space probe."

In contrast, Enceladus harbors a worldwide ocean of liquid water under a layer of surface ice, making this moon possibly the most important spot in the solar system to look for extant (Earth-like) extraterrestrial microorganisms. Consequently, the NASA-ESA team wanted to eliminate any chance of Earth hardware crashing onto Enceladus, and thus crashed Cassini into Saturn's atmosphere.

David Warmflash

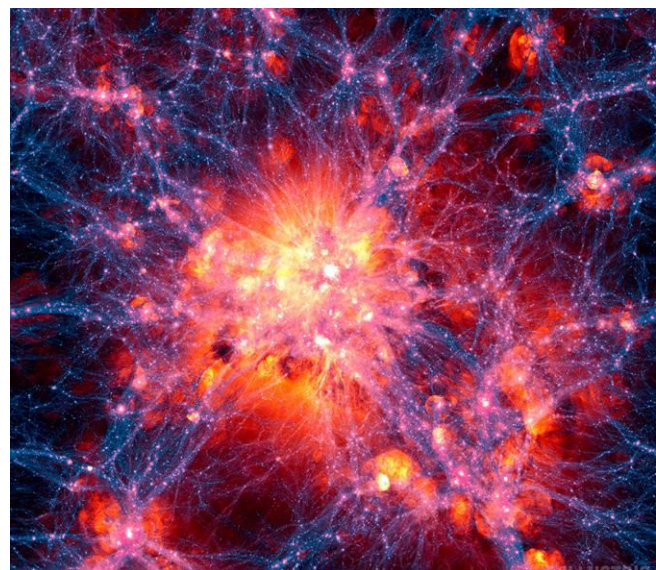
Astrobiologist and Science Communicator, Portland, Oregon

Q | WHAT IS THE COSMIC WEB COMPOSED OF?

*Babak Emami
Seattle, Washington*

A | Large observation programs that map the universe reveal that the distribution of galaxies is far from random. Such a deviation from randomness is called the universe's large-scale structure, and the cosmic web is a building block of this structure.

In order of abundance, the cosmic web is composed of dark matter, gas, and galaxies. Dark matter, which makes up about five-sixths of the mass, does not interact with light but dominates the gravitational pull of the cosmic web. Dark matter provides the scaffolding for the



formation of galaxies and galaxy clusters. The rest (one-sixth) of the cosmic web consists of normal matter: baryons (such as protons and neutrons) and electrons. It exists either in the form of intergalactic gas or as the stars and interstellar medium (gas and dust) in galaxies.

The gas in the cosmic web can be hot or cold, depending on its location. Gas within galaxy clusters is typically very hot, in the range of tens of millions of degrees. This material is known as intracluster gas or the intracluster medium (ICM). The ICM emits X-rays that can be observed, and it provides a way to study the distribution of mass within clusters and the history of cluster formation. The ICM also plays an important role in the evolution of galaxies within the cosmic web, as it can strip gas out of galaxies and prevent the formation of new stars.

Conversely, the gas in the filaments of the cosmic web connects galaxy clusters and superclusters, and it is typically colder, ranging from thousands to tens of thousands of degrees. This gas is known as the warm-hot intergalactic medium (WHIM). The WHIM is difficult to observe directly because it is not as hot or as dense as the gas in the ICM, and the light it emits does not penetrate very far into the universe before being absorbed. Nevertheless, the WHIM is believed to be a significant reservoir of baryonic matter in the universe. It may also play an important role in the growth of galaxies by providing a source of fuel for the formation of new stars.

Galaxies are grouped in clusters and superclusters and embedded within this cosmic web. Throughout their lifetime, galaxies continuously interact with the gas in the cosmic web: Gas from the web falls into galaxies to make stars, and gas within galaxies is ejected into the cosmic web by the winds from supernovae and active supermassive black holes. These interactions may hold the key to understanding the evolution of galaxies.

Donghui Jeong

*Associate Professor, Department of Astronomy and Astrophysics,
Penn State, University Park, Pennsylvania*

Q | THE APRIL ISSUE FEATURES A JWST IMAGE OF A STAR EARLY IN ITS DEVELOPMENT. IF PROTOSTARS DO NOT GENERATE THEIR OWN ENERGY THROUGH NUCLEAR FUSION YET, WHAT PRODUCES THE INFRARED LIGHT CAPTURED BY THE TELESCOPE?

Daniel Smith
Rome, New York

A | Stars form from massive clouds of cold gas and dust. These clouds are so cold that their temperatures hover around 10 kelvins (some minus 442 F, or minus 263 C). When parts of a cloud collapse into denser regions — and there are various ways this



might happen — the molecules within these collapsing portions begin to heat up. As molecules essentially fall toward each other into a clump, the pressure in the gas goes up as more mass is added. Increasing pressure causes the gas to heat up, and this heat is what generates the light the James Webb Space Telescope (JWST) sees.

JWST is perfect for studying protostars for two reasons. First, although protostars are certainly hotter than their surroundings, their temperature increases slowly and initially reaches only a few thousand degrees — not nearly hot enough to ignite fusion, which requires temperatures above 10 million K (nearly 18 million F, or 10 million C). Such low temperatures mean that much of the light a protostar puts out is at infrared wavelengths — the exact range in which JWST observes.

Second, any optical light a protostar does emit is absorbed by a thick envelope of gas and dust, which heats up slightly and reemits the remaining energy at longer wavelengths — again, much of which is in the infrared regime. So JWST is capturing both light from the protostar and emission from the warm gas and dust surrounding it.

Once a protostar gains enough mass for the corresponding pressure in its core to heat it to temperatures high enough for fusion, the energy created through fusion generates an opposing pressure that prevents further collapse, and a stable star is born. This can take millions or tens of millions of years!

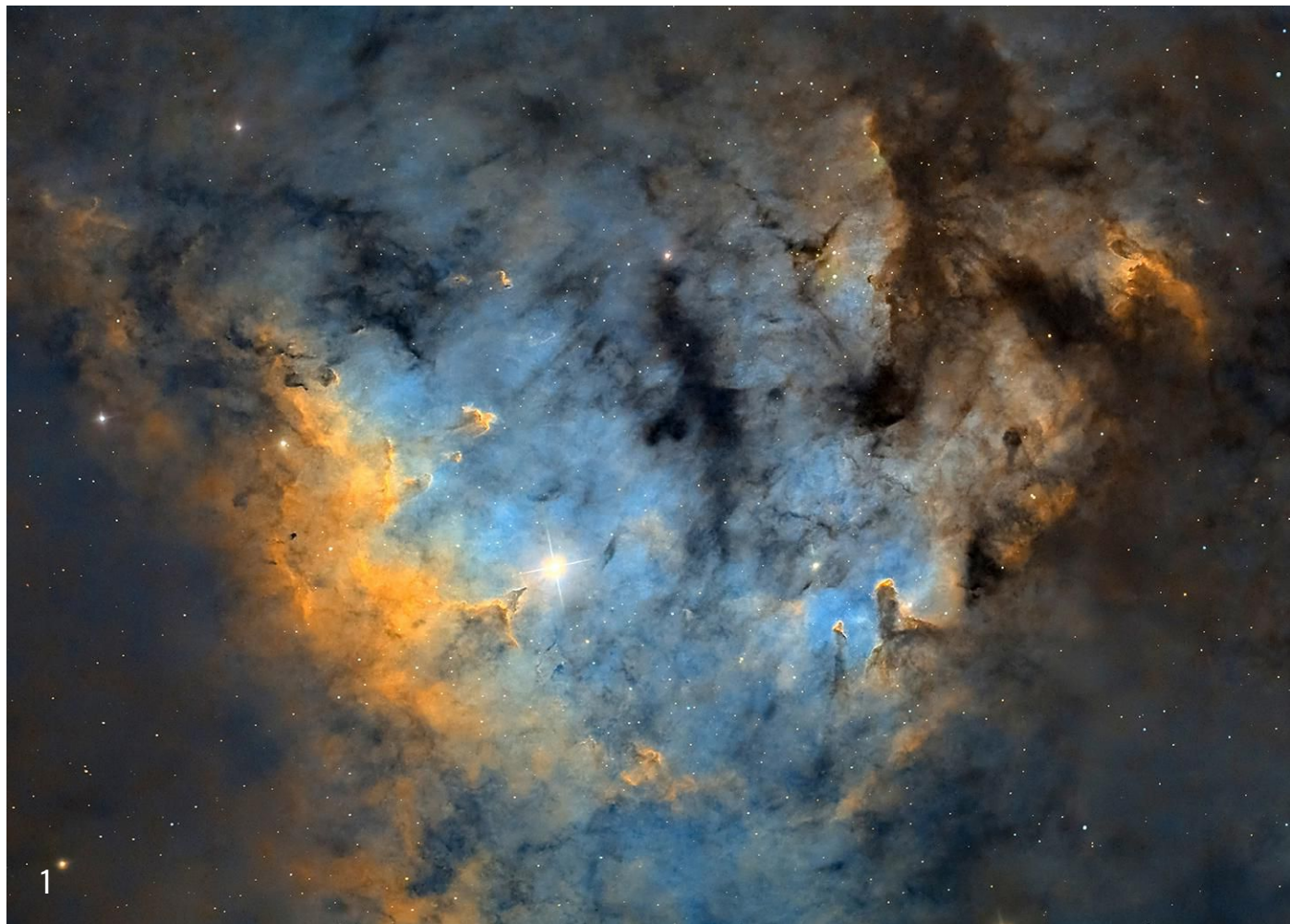
Alison Klesman
Senior Editor

JWST took this infrared image of the famous Pillars of Creation. It shows young, newly formed stars as well as the gas and dust from which they are born. Protostars embedded within the pillars are heating the gas (bright orange-red areas). NASA, ESA, CSA, STSCI; JOSEPH DEPASQUALE (STSCI), ANTON M. KOEKEMOER (STSCI), ALYSSA PAGAN (STSCI)

SEND US YOUR QUESTIONS

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Cosmic portraits



1. A STRIKING RESEMBLANCE

No, these aren't the Pillars of Creation in the Eagle Nebula (M16) — this is emission nebula NGC 7822, roughly 3,000 light-years distant in Cepheus. The imager used an 8-inch scope and 15.9 hours of exposure in the Hubble palette. • *Massimo Di Fusco*

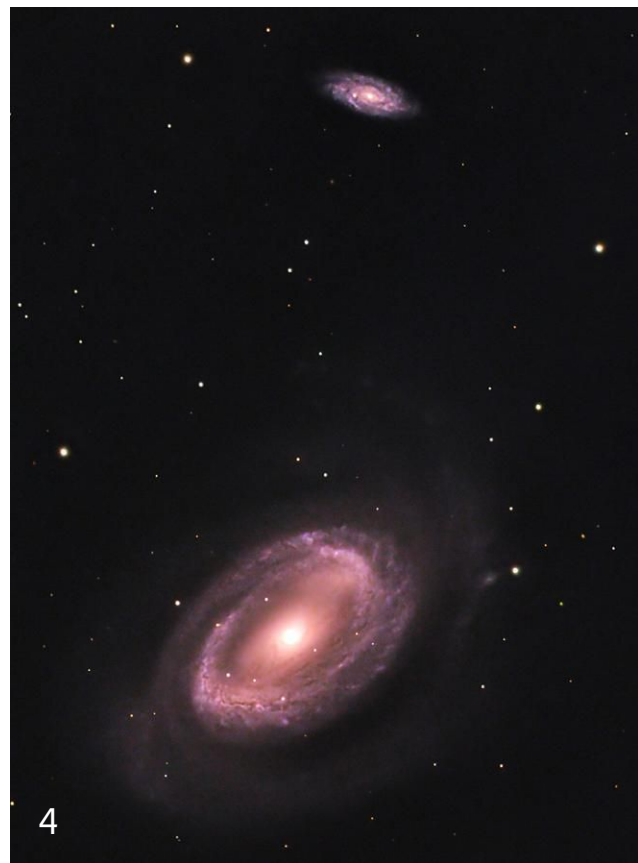
2. SPACE INVADERS

The remote village of Hanle in the Ladakh region of India is home to the country's first dark sky reserve, but it is not immune to satellite streaks, as this 30-minute composite exposure shows. • *Basudeb Chakrabarti*

3. THE FORSAKEN NEBULA

IC 5068 in Cygnus sits only about 1° away from the ever-popular Pelican (IC 5070) and North America (NGC 7000) nebulae. This image represents 14.3 hours of exposure with a 14-inch scope in the Hubble palette. • *Vikas Chander*





4. TAKE A BOW

NGC 4725 in Coma Berenices tilts dramatically toward us in this LRGB image of nearly 12 hours of integration with an 8-inch scope. NGC 4712 at the top of frame lies in the background, roughly five times farther. • *David Joyce*

5. RED VS. BLUE

The emission nebula Sh 2-150 and the reflection nebula VdB 154 in Cepheus make for a cosmic color clash between the red glow of hydrogen and blue light from massive young stars. This H α RGB image comprises 20 hours of exposure with a 3.9-inch scope. • *Bill Batchelor*

6. REVEALING VENUS

Venus' changing cloud tops — as well as its phases — show themselves in this false-color sequence taken with UV and IR filters. The imager processed the UV data as blue, the IR as red, and combined the two for a synthetic green channel. • *Konstantinos Beis*



SEND YOUR IMAGES TO:
readergallery@astronomy.com.

Please include the date and location of the image and complete photo data: telescope, camera, filters, and exposures.



A COLORFUL COSMIC CRUSTACEAN

A 1-pound female Maine lobster can carry about 8,000 eggs, though only a handful will develop into delicious adults. In this respect, the Lobster Nebula (NGC 6357) in Scorpius puts its earthly namesake to shame. This giant star-forming region has already birthed thousands of stars, and tens of thousands more wait in the wings. Most of them lie hidden within the ruddy glow of ionized hydrogen and thick clouds of dust. Even the open star cluster Pismis 24, which holds some of the Milky Way's most massive stars, barely shines through the yellowish cloud at the center of this visible-light image. (The bright stars with bluish halos are foreground objects.) NGC 6357 lies 8,000 light-years from Earth and spans 400 light-years. CTIO/NOIRLAB/DOE/NSF/AURA

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December 2023

Gas giants reign supreme



The bright stars of Orion and Canis Major dominate the eastern evening sky during December. If you're in the mood for planets, however, you'll want to turn your attention to the north and west.

First set your sights on **Jupiter**. The solar system's largest planet lies due north and about halfway to the zenith as twilight fades to darkness. It shines at magnitude -2.7 , far outpacing any nighttime star. The giant planet moves slowly westward against the backdrop of Aries the Ram, above the familiar trio of Alpha (α), Beta (β), and Gamma (γ) Arietis.

The best time to view Jupiter through a telescope comes when it lies highest in the north in early evening. Look for the planet's noticeably flattened disk, which spans $46.3''$ across the equator and $43.3''$ through the poles in mid-December. The gas giant's atmosphere resolves into an alternating series of dark belts and lighter zones that run parallel to the equator. Also keep an eye out for Jupiter's four bright Galilean moons.

Gaze well to the left and slightly below Jupiter and your eyes will fall on **Saturn**. The ringed planet edges eastward relative to the background stars of Aquarius the Water-bearer this month. At magnitude 0.8 , Saturn appears some seven times brighter than the brightest suns in this sprawling constellation.

Most observers think Saturn's telescopic appearance

outdoes Jupiter's. Even the smallest scopes reveal the planet's $17''$ -diameter disk encircled by a ring system that spans $37''$. The 8th-magnitude moon Titan also shows up easily. With a 10-centimeter or larger instrument, the 10th-magnitude trio of Tethys, Dione, and Rhea also comes into view.

Innermost **Mercury** joins Jupiter and Saturn in the evening sky, but you'll have to look harder to find it. The smallest of the major planets reaches greatest elongation December 4, when it lies 21° east of the Sun and stands 10° high in the west-southwest 45 minutes after sunset. It shines at magnitude -0.4 and shows up fairly well in the twilight.

When viewed at greatest elongation, a telescope shows the planet's $6.6''$ -diameter disk and slightly gibbous phase. During December's second week, Mercury appears a bit larger and sports a pleasing crescent shape. The inner world disappears soon after, however, as it heads toward inferior conjunction with the Sun on the 22nd.

You'll have to wait for the early morning hours to catch **Venus**. It begins the month against the backdrop of Virgo, below the Maiden's luminary, 1st-magnitude Spica. Gleaming at magnitude -4.2 , the planet shines some 100 times brighter than the star. Venus moves eastward all month, crossing the border into Libra the Balance on December 11. The

day before, a pretty crescent Moon passes near Venus.

The inner planet's distance from Earth grows this month, so its apparent size shrinks. On December 1, its disk spans $17''$ and looks two-thirds lit. By the 31st, it shows a $14''$ -diameter disk that's slightly more than three-quarters illuminated.

You won't see **Mars** this month as it continues orbiting on the far side of the Sun from our perspective.

The starry sky

I have written often about Eridanus the River. This constellation begins just west of Rigel in Orion the Hunter and meanders southward all the way to Achernar. At least it does now. Originally, the River ended at Acamar (Theta [0] Eridani). Both names translate to "end of the river."

Magnitude 0.5 Achernar ranks as the ninth-brightest star in the night sky. Because it appears isolated, it doesn't get the attention of Alpha and Beta Centauri or Crux the Cross. Nevertheless, December evenings offer a great chance to view this luminary as it rides high in the north once darkness falls.

Achernar proves useful for celestial navigators as a convenient way to locate the South Celestial Pole. Start at the bright star and then head south (below when Achernar is due north) 15° — about three-quarters of your hand's span when held at arm's length. That gets you to

the Small Magellanic Cloud. Drop an equal distance south and you'll reach the pole.

Astronomers take great interest in Achernar because it is the brightest and closest "Be star." These hot B-type suns rotate rapidly and have emission lines in their spectra.

The first Be star discovered was Gamma Cassiopeiae. It lies so far north that it never rises from mid-southern latitudes and appears only low in the north if you live closer to the equator. Achernar, on the other hand, is circumpolar for many southerners.

Because they rotate so rapidly, Be stars have disks that appear considerably flattened. In Achernar's case, its equatorial diameter is about 50 percent greater than its polar diameter.

The emission lines in the spectra of Be stars come from a gaseous disk surrounding the star. The fast rotation ejects material from the star's equatorial regions. Astronomers estimate that Achernar spins at more than 225 kilometers per second, completing a single rotation in about two days. Compare that with the smaller Sun, whose equator takes 24.5 days to rotate.

Although you can't see these effects through an amateur telescope, it's still worth gazing high in the sky and contemplating how important Eridanus' luminary is to our understanding of these impressive stars. ☛

STAR DOME

HOW TO USE THIS MAP

This map portrays the sky as seen near 30° south latitude. Located inside the border are the cardinal directions and their intermediate points. To find stars, hold the map overhead and orient it so one of the labels matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

The all-sky map shows how the sky looks at:

11 P.M. December 1
10 P.M. December 15
9 P.M. December 31

Planets are shown at midmonth

MAP SYMBOLS

- Open cluster
- ⊕ Globular cluster
- Diffuse nebula
- ⊕ Planetary nebula
- Galaxy

STAR MAGNITUDES

- Sirius
- 0.0 ● 3.0
- 1.0 ● 4.0
- 2.0 ● 5.0

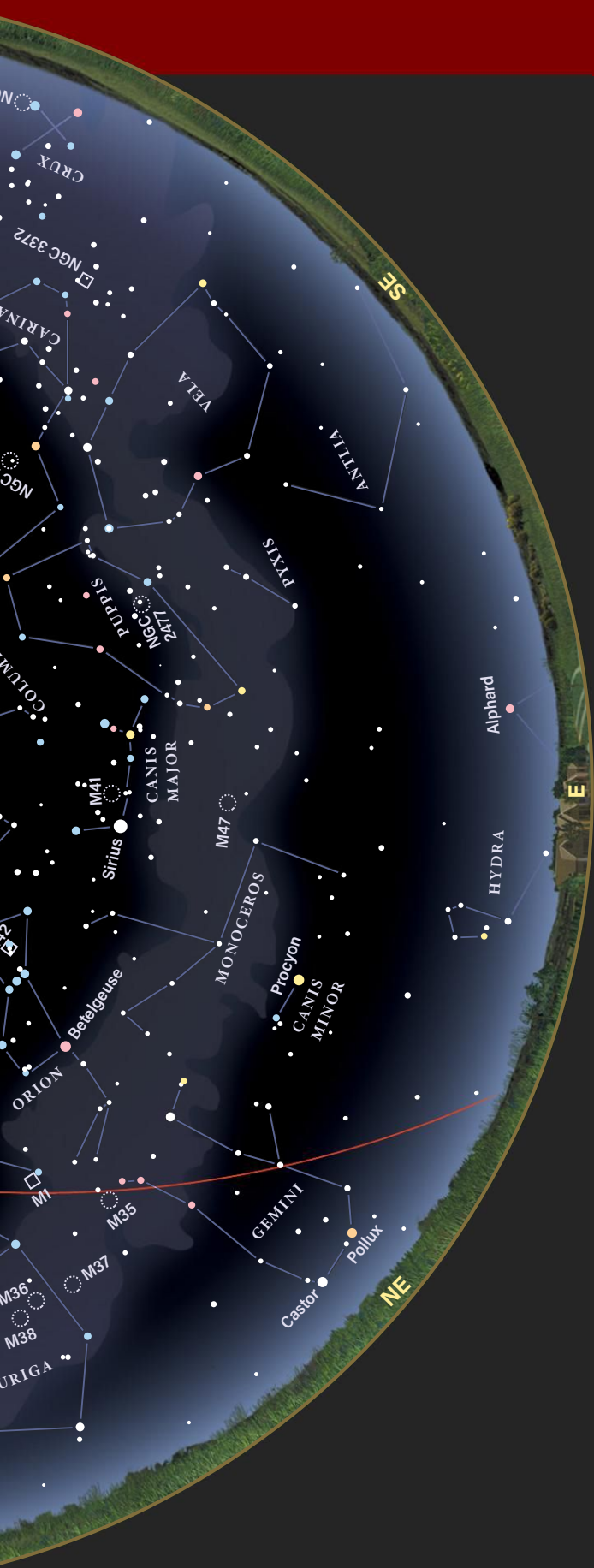
STAR COLORS

A star's color depends on its surface temperature.

- The hottest stars shine blue
- Slightly cooler stars appear white
- Intermediate stars (like the Sun) glow yellow
- Lower-temperature stars appear orange
- The coolest stars glow red
- Fainter stars can't excite our eyes' color receptors, so they appear white unless you use optical aid to gather more light



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DECEMBER 2023

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ILLUSTRATIONS BY ASTRONOMY: ROEN KELLY

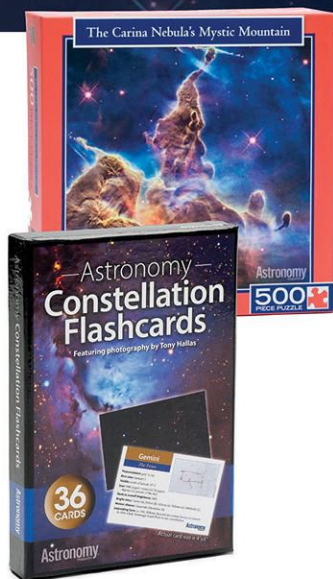
Note: Moon phases in the calendar vary in size due to the distance from Earth and are shown at 0h Universal Time.

CALENDAR OF EVENTS

- 4** Mercury is at greatest eastern elongation (21°), 14h UT
The Moon is at apogee (404,346 kilometers from Earth), 18h42m UT
- 5**  Last Quarter Moon occurs at 5h49m UT
- 7** Neptune is stationary, 0h UT
- 9** The Moon passes 4° south of Venus, 17h UT
- 12**  New Moon occurs at 23h32m UT
- 13** Mercury is stationary, 5h UT
- 14** The Moon passes 4° south of Mercury, 5h UT
Geminid meteor shower peaks
- 16** The Moon is at perigee (367,901 kilometers from Earth), 18h53m UT
- 17** The Moon passes 2° south of Saturn, 22h UT
- 19** The Moon passes 1.3° south of Neptune, 13h UT
 First Quarter Moon occurs at 18h39m UT
- 21** Asteroid Vesta is at opposition, 19h UT
- 22** Summer solstice occurs at 3h27m UT
The Moon passes 3° north of Jupiter, 14h UT
Mercury is in inferior conjunction, 19h UT
Asteroid Metis is at opposition, 23h UT
- 23** The Moon passes 3° north of Uranus, 15h UT
- 27**  Full Moon occurs at 0h33m UT
Asteroid Astraea is at opposition, 22h UT
- 31** Jupiter is stationary, 15h UT

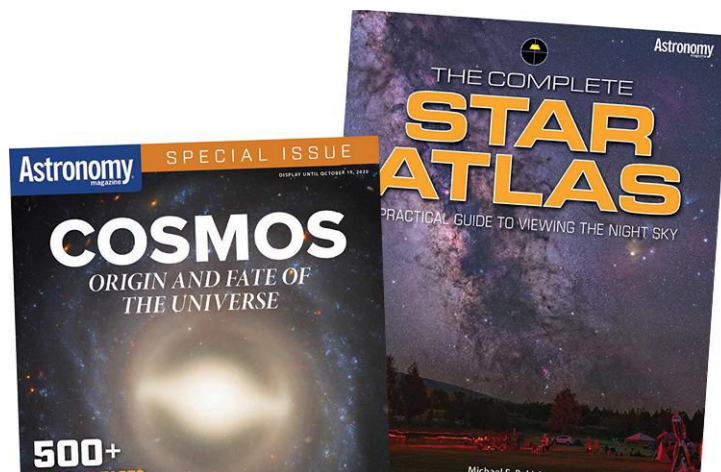
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